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TRENDS ANALYSIS METHODOLOGY FOR WATER QUALITY TIME SERIES

R. A. C. PROJECT NO. 278C

Prepared for Environment Ontario by:

McLeod-Hipel & Assoc. Ltd.

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R.A.C. PROJECT NO. 278C

Report prepared for Environment Ontario by:

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ABSTRACT

A general trend analysis methodology is presented for detecting and modelling trends in water quality time series observed in rivers and streams. The procedure is specifically designed for typically ill-behaved river quality series characterized by such problematic features as non-normal positively skewed populations, irregularly spaced instantaneous observations, seasonal periodicities and covariable, e.g. discharge, dependence. Within the main steps of the methodology, specific graphical, parametric and nonparametric statistical techniques are utilized. Graphical methods include time series plots, robust regression smooths and box and whisker plots. Nonparametric techniques include tests based on Kendall's τ rank correlation coefficient. An innovative procedure based on Spearman's partial rank correlation is introduced as a means of 'partialling out' , i.e. eliminating, seasonal effects and testing for the presence of trend. The methods are illustrated by application to a variety of fundamental water quality indicator variables observed in the Grand and Saugeen Rivers of southwestern Ontario, Canada.

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1. INTRODUCTION

The Ministry of the Environment within the Canadian Province of Ontario operates a spatially and temperally extensive sampling network called the Provincial Water Quality Monitoring Network or simply PWQMN. Approximately one sample per month is collected at over 700 sites, which may be analyzed for up to 60 water quality indicator parameters. In fact, the PWQMN is one of the world's largest water quality sampling networks falling under the umbrella of a single political jurisdiction.

Large sums of money are being spent on collecting substantial data through the PWQMN. To make this data meaningful and useful, they must be properly summarized and analyzed. The Ministry of the Environment, as well as many other organizations, are especially interested in detecting and modelling historical trends in PWQMN data. Trend analyses are required for alerting authorities about water quality degradation so that appropriate corrective action can be taken and for evaluating the performance of pollution abatement schemes.

The major objective of this study is to develop a general trend analysis methodology for analyzing trends in water quality time series measured in rivers. Furthermore, to demonstrate the efficacy of the new methodology, it is applied to representative PQWMN time series.

The underlying conceptual model used in trend analysis of a water quality variable X can be written as

$$X_t=C_t+S_t+T_t+\varepsilon_t \tag{1.1}$$

where X_t is the water quality observation at time t, C_t is a covariate series at time t such as riverflow or temperature, S_t is the seasonal component at time t, T_t is the trend in X_t, and ε_t is the noise component at time t. In trend analysis, one wishes to appropriately account for C_t, S_t and ε_t so that T_t can be easily detected and accurately quantified, even when the trend effects are small. Trends over time can be increasing, decreasing or non-existent. Furthermore, trends over time can follow linear or nonlinear geometrical patterns. For the purpose of the data analyzed in this study, the covariate series used is flow. However, in other situations, different covariate series can be used. For example, temperature may be better to use as C_t when the X_t series is dissolved oxygen or total nitrates. Also, when water quality measurement sites are far removed from flow gauging sites, covariates other than flow may have to be used for C_t.

In Section 3, the general trend analysis methodology is described. As explained in that section and outlined in Table 3.1, the methodology consists of the two main steps of graphical trend studies and trend tests. Sections 2.2 and 2.3 describe specific graphical and statistical trend tests, respectively, that can be used in the overall methodology. Procedures are also given for accounting for the effects of flow or another appropriate covariate upon a given water quality series and eliminating any trend in the flow before its affect upon the water quality series is removed. In Section 2.3.7, a powerful test based on the Spearman partial rank correlation test is described for use in trend detection when possible seasonality is present.

As pointed out in Section 2.1, environmental data are often very "messy". They may, for example, have many missing values and outliers, besides being nonnormally distributed. To develop a comprehensive trend analysis methodology for employment with messy data, a systems design approach to algorithmic development was followed. Based upon their previous experience in environmental impact assessment, the authors outlined a rough procedure to follow. However, as a result of many complex problems encountered when analysing PWQMN data, the authors drastically altered and expanded the procedure to arrive iteratively at a comprehensive trend analysis methodology. Many unique features of the methodology are summarized in Section 5.

Eight PWQMN water quality time series (see Table 4.1) as well as riverflows are analyzed in depth for two rivers located in Southern Ontario. In particular, the two PWQMN sites are the Saugeen River at Burgoyne and the Grand River at Dunnville. The data at these sites are selected for study because flow biased monitoring is used. This means that more samples are collected at high flows for the purpose of mass-discharge estimation. Hence, the data collected at these high frequency monitoring sites should contain greater relevant information and their analyses should provide insight into how to analyze both highly monitored and less frequently monitored sites. Representative trend analysis results are employed in Section 3.2 for explaining how to apply the methodology. In Section 4, the main findings for all the series are summarized while detailed trend analysis output for each series is given in the Appendix.

Trend analyses are required for determining whether a given water quality variable is improving or getting worse. A practical illustration of where trend analysis is needed is a water quality agreement between Canada and the U.S.. Under Annex 3 of the 1987 amendments to the 1978 Canada-U.S. Great Lakes Water Quality Agreement, Canada and Ontario are committed to an annual 200 tonne reduction in nonpoint source phosphorus loadings into Lake Erie. Because these phosphorus loadings are largely driven by high flow runoff events, they possess great stochastic variability, as is the case for the measurements taken on the Saugeen and Grand Rivers. To reduce phosphorus levels caused by nonpoint sources, appropriate land use practices are being systematically implemented at various locations over time. This in turn means that there should be a gradual decline in phosphorus levels over a long time period. The detection of this possible slowly decreasing trend against a background of high stochastic variation demands that powerful and sophisticated techniques be available for trend detection. As is done using the flexible methodology developed in this project, as much of the systematic variation embedded in a given water quality series, such as phosphorus, is removed prior to trend testing in order to detect subtle trend effects. For the case of total phosphorus, slightly decreasing trends are found using the methodology developed in this project in both the Saugeen and Grand Rivers.

2. DATA ANALYSIS

2.1 Exploratory and Confirmatory Data Analyses

Water quality and other kinds of environmental time series often possess characteristics which do not allow the series to be easily analyzed using statistical techniques (Lettenmaier, 1976; Hirsch et al., 1982; McLeod et al., 1983; Van Belle and Hughes, 1984; Hirsch and Slack, 1984; El-Shaarawi and Kwiatowski, 1986; Hipel, 1988, Hipel et al. 1988). One of the major problems with these time series is that there are often many missing data points among which there may be long periods of time for which no observations were taken. Water quality data may be non-normally distributed and follow a distribution which is usually positively skewed. In addition, the data are often censored by only listing measurements below a certain level as being "less than" of measurements above a specified level as being "greater than". For instance, concentration values for toxic compounds, metals or organic compounds which fall below the limits of detection for certain chemical tests are reported simply as less than the limits of detection. Seasonality effects contained in a sequence of measurements over the years can cause cyclic patterns to appear in a graph of a given water quality variable. When there are many different water quality variables interacting with one another in the presence of varying flow rates, the multivariate effects of the interactions can be quite complex. As a further major complication, one or more external interventions may significantly affect the stochastic manner in which a series behaves and thereby create a variety of trends. Because of the foregoing and other reasons, environmental data are often quite "messy".

In the previous paragraph, it is mentioned that messy environmental data often possess "missing" values. What is meant by "missing" observations must be explained in more detail, especially for the case of water quality time series. First, consider what missing means with respect to parametric techniques. For many parametric methods, such as the wide variety of time series models, it is usually assumed that observations are available at equally spaced time intervals. For example, when fitting a periodic autoregressive model to average monthly riverflow series, all of the monthly observations across the years must be available. If there is at least one missing observation, the data are no longer evenly spaced due to this missing value. Before fitting the time series model, one must obtain estimates for the missing value or values. Furthermore, for the case of riverflows usually each monthly observation is calculated as a monthly average of average daily flows. Each daily average may be based upon a continuous record taken for that day. Hence, the monthly flow data are often calculated from continuous analogue records.

In contrast to riverflow records, water quality observations usually have quite different meanings in sampling theory. More specifically, most water quality records could be classed as irregular series of "quasi-instantaneous" measurements. This is because each water quality sample takes about 10 to 15 seconds to collect. With such samples, the term "missing data" could refer to a number of situations including:

1. all the unsampled 10 to 15 second periods of the record. This total number is, of course, very large and can be thought of as infinity for practical purposes.
2. uncollected or lost samples with respect to a specific monitoring objective. For instance, an objective may be to collect one sample per month and if at least one monthly observation is missing the data are irregularly spaced due to this missing value. Another objective may be to have most of the water quality samples taken during times of high flows to produce flow biased data. If no samples are taken for at least one high flow event, then there is missing data.

3. data missing in the sense of some analytical framework. For example, suppose that the framework chosen is the monthly level. If there is at least one observation per month, then one can say that there are no missing values. However, at a daily level there may be many missing observations.

Another stated characteristic of "messy" environmental data is that the observations may be significantly affected by external interventions. These interventions may be man-induced or natural. An example of a beneficial man-induced intervention is the introduction of tertiary treatment on city sewage plants located in a river basin. This beneficial intervention should cause a step decrease in the phosphorus levels in the river. On the other hand, uncontrolled industrial development with few environmental controls would cause detrimental effects upon certain water quality variables in a river. One can cite many other examples of environmental policy and related land use changes which can adversely or beneficially affect water quality. An illustration of a natural intervention is the affect of a forest fire in a river basin upon water quality variables. For example, the resulting lack of forest cover may cause more sediments to be carried and deposited by rivers. However, as a new forest grows back over the years, the flows and water quality variables may slowly revert to their former states. In trend analysis one wishes to detect and analyze trends caused by man-made or natural interventions.

In order to extract an optimal amount of information from messy environmental data, a systems design approach to data analysis can be followed. As proposed by Tukey (1977) and demonstrated by authors such as McLeod et al. (1983) and Hipel et al. (1988) using water quality data, the two major steps in a statistical study consist of exploratory and confirmatory data analysis. The objective of the exploratory data analysis stage is to employ simple graphical and numerical techniques to discover important patterns and statistical characteristics such as the presence of trends. The purposes of the confirmatory data analysis stage are to confirm statistically in a rigorous fashion the presence or absence of certain properties in the data. Depending upon the quantity and quality of the data being analyzed, appropriate graphical parametric and nonparametric techniques can be employed as exploratory and confirmatory data analysis tools.

As noted in the introduction, the major objective of this study is to develop a procedure for analyzing trends in water quality time series. The flexible and comprehensive trend analysis procedure presented in Section 3 utilizes both exploratory and confirmatory data analysis tools. In Section 2.2, the graphical exploratory data analysis methods used in the trend analysis procedure are described. Following this, the nonparametric and parametric statistical tests that can be used in the procedure to confirm statistically the presence of trends are presented in Section 2.3.

Some statistical tests require that the data be approximately normally distributed. If a time sequence of observations is not normal or Gaussian, one approach to cause the data to become approximately normally distributed is to invoke a Box-Cox power transformation (Box and Cox, 1964). Let x_t represent a time series consisting of n values $x_1, x_2, \ldots, x_n$. A Box-Cox power transformation is defined as

$$x_t^{(\lambda)}=\begin{cases}\lambda^{-1}[(x_t+c)^{\lambda}-1] & \lambda\neq 0\\ \log(x_t+c) & \lambda=0\end{cases} \qquad (2.1)$$

where c is a constant that is chosen just large enough to cause all of the entries in the series to be positive. If there are no zero or negative entries in the original series that c is simply assigned a value of zero. Notice that when the lambda exponent denoted by λ in Equation 2.1 is equal to zero, this is a natural logarithmic transformation. A square root transformation is given by $\lambda=0.5$.

As explained in Section 2.2.3, one method to ascertain whether or not a Box-Cox transformation is needed is to employ box and whisker graphs. Non-normality can also be detected from a plot of a series (Section 2.2.1). One can select a value of λ which causes the resulting transformed series to become approximately normally distributed. In practice, therefore, it may be necessary to try a few different values of λ in order to determine the most appropriate one. In some situations, one may know beforehand which value of λ to select. For instance, average monthly riverflows usually require a logarithmic transformation (i.e. $\lambda=0$ in Equation 2.1). When one is using a parametric model such as a specific time series model, one may be able to obtain a maximum likelihood estimate for λ.

2.2 Graphical Methods

2.2.1 Time Series Plot

One of the simplest and most informative exploratory data analysis tools is to plot the data against time. Characteristics of the data which are often easily discovered from a perusal of a graph include the detection of extreme values, trends due to known or unknown interventions, dependencies between observations, seasonality, need for a data transformation, nonstationarity and long term cycles (McLeod et al., 1983; Berthouex et al., 1981).

A time series plot is especially useful for visually detecting the presence or absence of a trend. Figure 2.1, for example, shows a graph of total nitrates for the Saugeen River against time, where each observation is matched using a cross. The fact that $\lambda=0$ is written above the graph means that the natural logarithmic transformation from Equation 2.1 is invoked. The two horizontal lines plotted in the graph delineate the 95% confidence interval (CI) limits if the series is assumed to be normally independently distributed (NID). The method for calculating the 95% CI is explained in a subsection below. The observations that lie far outside the 95% CI in Figure 2.1 can be considered as outliers under the assumption that the data are NID.

In Figure 2.1, there is one particularly large observation occurring in 1982. One may wish to examine the records to see if this observation is correct. If the extreme observation were erroneous, one could remove it from the record and thereby not use it in subsequent data analysis. However, the techniques from Sections 2.2 and 2.3 used in the general trend analysis procedure of Section 3 are robust or insensitive to outliers. Therefore, this extreme value, or others, is not eliminated from the record.

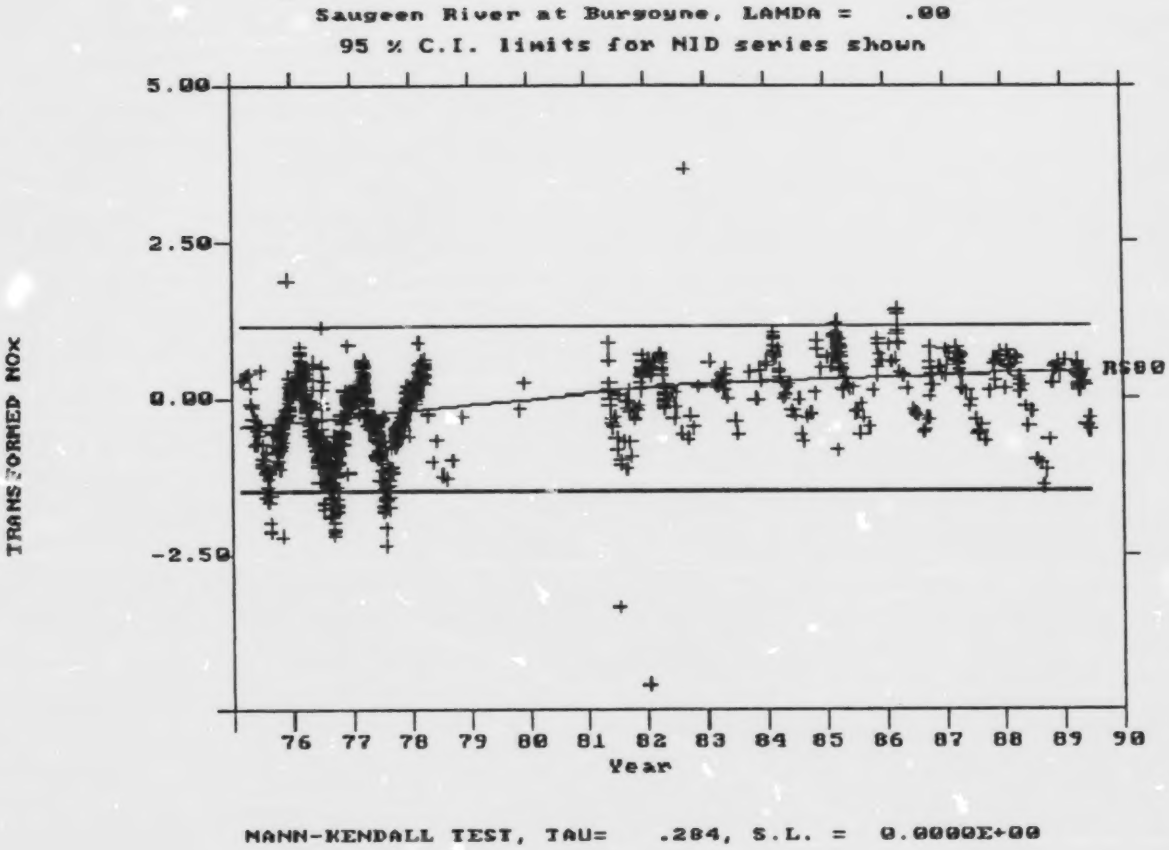

Figure 2.1. Graph of logarithmic total nitrates denoted by NO_x (mg/l) against time.

Notice that there appears to be an upward trend, as indicated by the rising line. This line is referred to as a robust locally weighted regression smooth (RLWRS) and the theory behind a RLWRS (Cleveland, 1979) is summarized below under the section entitled scatter plot. Bodo (1989) also provides a brief explanation of the RLWRS.

As shown by the dark mass of crosses in the earlier years, more observations were taken at that time. The large gap between many observations, especially in the period from 1979 to 1981, shows that there are time periods during which few measurements were taken and, therefore, the sequence of observations are unequally spaced. The sinusoidal cycle, which is especially pronounced during the first few years, means that the logarithmic total nitrate data are seasonal.

The results of the nonparametric Mann-Kendall test written below the graph in Figure 2.1 confirms that there is an upward trend. This is because the value of the statistic tau is positive and the significance level (SL) for this monotonic trend test is close to zero. A small SL (for example, a value less than 0.05) means one should reject the null hypothesis that there is no trend and accept the alternative hypothesis that there is a trend (see Section 2.3.2). Alternatively, if the SL level is large and greater than say 0.05, one should accept the null hypothesis that there is no trend. The Mann-Kendall test should only be used when the data are not seasonal. Hence, for this case, the result of the test is only a rough indicator for confirming the presence of a monotonic trend. The Mann-Kendall trend test is described in Section 2.3.2.

95% Confidence Interval (CI)

As in Equation 2.1, let x_t represent a time series consisting of n values. The mean of the series is estimated as

$$\bar{x}=\frac{1}{n}\sum_{t=1}^{n}x_t \tag{2.2}$$

The variance of the series is estimated using

$$\hat{\sigma}_x^2=\frac{1}{n}\sum_{t=1}^{n}(x_t-\bar{x})^2 \tag{2.3}$$

The estimated standard deviation, $\hat{\sigma}_x$, is simply the square root of the variance.

In a normal distribution, the only two parameters are the mean and the variance. 95% of the area under a normal probability curve lie between $\bar{x}-1.96\hat{\sigma}_x$ and $\bar{x}+1.96\hat{\sigma}_x$. Consequently, to plot the 95% CI shown in Figure 2.1, one simply plots lines that lie $1.96\hat{\sigma}_x$ above and below the mean $\bar{x}$. To avoid cluttering in a time series plot, the mean line, which lies at the midpoint of the 95% CI, is not shown. Furthermore, when plotting a CI in this manner it is assumed that the data are independently distributed. If they aren't, many of the plotted values could fall outside the 95% CI.

2.2.2 Scatter Plot

Robust Locally Weighted Regression Smooth

Introduction: Suppose that two variables that can be samples are denoted by X and Y. The measurements for these variables are given by (x_i,y_i), $i=1,2,\ldots,n$. In a scatter plot, the values for the X and Y variables can be plotted as the abscissae and ordinates, respectively. To gain insight into the relationship between X and Y, it is informative to plot some type of smoothed curve through the scatter plot. In the final part of the section, it is explained how smoothed curves can be obtained for a graph of a single time series. However, for convenience and generality of presentation, developing a smoothed curve for (x_i,y_i) is now discussed.

A flexible type of smoothing procedure which works well in practice is the robust locally weighted regression smooth (RLWRS) developed by Cleveland (1979). Cleveland (1979, 1985), Chambers et al. (1983) and others refer to the general smoothing procedure as LOWESS although in this report the acronym RLWRS is employed. In essence, robust locally weighted regression is a method for smoothing a scatter plot of (x_i,y_i), $i=1,2,\ldots,n$, in which the fitted value at x_k is the value of a polynomial fitted to the data using weighted least squares. The weight for (x_i,y_i) is large if x_i is close to x_k and is small if this is not the case. To display graphically the RLWRS on the scatter plot of (x_i,y_i), one plots $(x_i,\hat{y}_i)$ on the same graph as the scatter plot of (x_i,y_i), where $(x_i,\hat{y}_i)$ is called the smoothed point at x_i and $\hat{y}_i$ is called the fitted value at x_i. To form the RLWRS, one simply joins successive smoothed points $(x_i,\hat{y}_i)$ by straight lines. Because a robust fitting procedure is used to obtain the RLWRS, the smoothed points are not distorted by extreme values or other kinds of deviant points.

General Procedure: As explained by Cleveland (1979), the general idea behind his smoothing procedure is as follows. Let W be a weight function which has the following properties:

1. $W(x)>0$ for $|x|<1$
2. $W(-x)=W(x)$
3. $W(x)$ is a nonincreasing function for $x\geq 0$.
4. $W(x)=0$ for $|x|\geq 1$.

If one lets $0<f\leq 1$ and lets r be fn rounded to the nearest integer, the outline of the procedure is as given below. For each x_i, weights, $w_k(x_i)$, are defined for all x_k, $k=1,2,\ldots,n$, by employing the weight function W. To accomplish this, center W at x_i and scale W so that the point at which W first becomes zero is the rth nearest neighbour of x_i. To obtain the initial fitted value, $\hat{y}_i$, at each x_i a dth degree polynomial is fitted to the data using weighted least squares with weights $w_k(x_i)$. This procedure is called locally weighted regression. Based upon the size of the residual $y_i-\hat{y}_i$, a different set of weights, δ_i, is defined for each (x_i,y_i). In general, large residuals cause small weights while small residuals result in large weights. Because large residuals produce small weights, the effects of extremes tend to be toned down or smoothed, thereby making the procedure robust. After replacing $w_k(x_i)$ by $\delta_i w_k(x_i)$, new fitted values are computed using locally weighted regression. The determination of new weights and fitted values is repeated as often as required. All of the foregoing steps are referred to as robust locally weighted regression.

In the smoothing procedure, points in the neighbourhood of (x_i,y_i) are used to calculate $\hat{y}_i$. Because the weights $w_k(x_i)$ decrease as the distance of x_k from x_i increases, points whose abscissae are closer to x_i, have a larger effect upon the calculation of $\hat{y}_i$ while further points play a lesser role. By increasing f, the neighbourhood of points affecting $\hat{y}_i$ becomes larger. Therefore, larger values of f tend to cause smoother curves.

In the RLWRS procedure, local regression means that regression at a given point is carried out for a subset of nearest neighbours such that the observations closer to the specified point are given larger weights. By taking the size of the residuals into account for obtaining revised weights, robustness is brought into the procedure. Finally, the robust locally weighted regression analysis is carried out for each observation.

Specific Procedure: The procedure presented by Cleveland (1979) for determining the RLWRS is as follows:

1. First the weight function, W, must be specified. Let the distance from x_i to the rth nearest neighbour of x_i be denoted by h_i for each i. Hence, h_i is the rth smallest number among $|x_i - x_j|$, for $j=1,2,\ldots,n$. For $k=1,2,\ldots,n$, let

$$w_k(x_i)=W((x_k-x_i)/h_i) \tag{2.4}$$

A possible form for the weight function, S, is the tricube given by

$$\begin{aligned} W(x)&=(1-|x|^3)^3 \quad \text{for } |x|<1 \\ &=0 \qquad\qquad\quad \text{for } |x|>1 \end{aligned} \tag{2.5}$$

2. The second step describes how locally weighted regression is carried out. For each i, determine the estimates, $\hat{\beta}_j(x_i)$, $j=0,1,\ldots,d$, of the parameters in a polynomial regression of degree d of y_k on x_k. This is fitted using weighted least squares having weight $w_k(x_i)$ for (x_k,y_k).. Therefore, the $\hat{\beta}_j(x_i)$ are the values of β_j which minimize

$$\sum_{k=1}^{n} w_k(x_i)(y_k-\beta_0-\beta_1x_k-\beta_2x_k^2-\cdots-\beta_dx_k^d)^2 \tag{2.6}$$

When using locally weighted regression of degree d, the smoothed point at x_i is $(x_i,\hat{y}_i)$ for which $\hat{y}_i$ is the fitted value of the regression at x_i. Hence,

$$\hat{y}_i=\sum_{j=0}^{d}\hat{\beta}_j(x_i)x_i^j=\sum_{k=1}^{n}r_k(x_i)y_k \tag{2.7}$$

where $r_k(x_i)$ does not depend on y_j, $j=1,2,\ldots,n$. Cleveland (1979) uses the notation $r_k(x_i)$ to reinforce the fact that the $r_k(x_i)$ are the coefficients for the y_k coming from the regression.

3. Let the bisquare weight function be given by

$$\begin{aligned} B(x)&=(1-x^2)^2 \quad \text{for } |x|<1 \\ &=0, \qquad\qquad \text{for } |x|\geq 1 \end{aligned} \tag{2.8}$$

Let the residuals for the current fitted values be $e_i=y_i-\hat{y}_i$. The robustness weights are defined by

$$\delta_k=B(e_k/6s) \tag{2.9}$$

where s is the median of the $|e_i|$. As pointed out by Cleveland (1979), other types of weight functions could be used in place of $B(x)$.

4. This step is used to calculate an iteration of robust locally weighted regression. For each i, determine new $\hat{y}_i$ by fitting a dth degree polynomial using weighted least squares having the weight $\delta_k w_k(x_i)$ at (x_k,y_k).

5. Iteratively execute steps 3 and 4 for a total of t' times. The final $\hat{y}_i$ constitute the fitted values for the robust locally weight regression and the $(x_i,\hat{y}_i)$ $i=1,2,\ldots,n$, form the RLWRS.

Selecting Variables: In order to employ the above procedure, one must specify f, d, t' and W. Cleveland (1979) provides guidelines for doing this. As noted earlier, an increase in f causes an increase in the smoothness of the RLWRS. The objective is to select a value of f which is as large as possible to minimize the variability in the smoothed points but without hiding the fundamental pattern or relationship in the data. When it is not certain which value of f to select, setting f=0.5 often produces reasonable results. In practice, one can experiment with two or three values of f and select the one which produces the most informative smooth. The robust smooth called RS80 in Figure 2.1 refers to a value of f=0.8. Hence, the number beside RS is the f value multiplied by 100.

Instead of qualitatively selecting one or more values of f, one can estimate f. Based upon the research of Allen (1974), Cleveland (1979) suggests an approach for automatically determining f using a computer program. The approach begins with the locally weighted regression in step 2. Leaving y_i out of the calculation, for a specified value of f let $\hat{y}_i(f)$ be the fitted value of x_i. A starting value of f_0 for f is chosen by minimizing

$$\sum_{k=1}^{n}(y_k-\hat{y}_k(f))^2 \tag{2.10}$$

Next, using $f=f_0$ the robustness weights in Equation 2.9 in step 3 can be determined. Omitting y_i from the calculation and using the robustness weights, let $\hat{y}_i(t)$ be the fitted value at x_i for a given value of f. The next value of f is determined by minimizing

$$\sum_{k=1}^{n}\delta_k(y_k-\hat{y}_k(f))^2 \tag{2.11}$$

Using the latest estimated value of f, the last step can be repeated as many times as are necessary in order to converge to a suitably accurate estimate for f. Depending upon the problem at hand, this procedure for estimating f may require substantial computational time.

The parameter d is the order of the polynomial that is locally fitted to each point. When d=1, a linear polynomial is specified. This usually results in a good smoothed curve that does not require high computational effort and, therefore, a linear polynomial is used.

The parameter t' stands for the number of iterations of the robust fitting procedure. Based upon experimentation, Cleveland (1979) recommends using t'=2. However, the authors of this report have found that t'=1 is sufficient for most applications.

In the description of the general procedure for RLWRS, four required characteristics of the weight function, $W(x)$, are given. It is also desirable that the weight function smoothly decreases to zero as x goes from 0 to 1. The tricube function in Equation 2.5 possesses all of the above stipulated properties. Of course, other appropriate weight functions possessing the above attributes could also be entertained.

Applications: The RLWRS can clearly depict meaningful relationships for the situations described below:

1. *Scatter Plot* of X against Y - Figure 2.2 shows a plot of the logarithmic flows of the Saugeen River (the X variable) against the logarithmic total nitrates (Y variable). The flows are only used for the same times at which the total nitrate measurements are available. Notice that there appears to be a nonlinear function relationship between the flows and the nitrates. To allow the RLWRS to follow this relationship a graph using RS50 is employed. A visual examination of this RLWRS shows that the extreme values do not adversely affect it. The Kendall rank correlation test given at the bottom of Figure 2.2 is described in Section 2.3.3. Because tau is positive, there is an upward trend in the scatter plot. The fact that the SL is very small means that the relationship is significant.
2. *Time Series Plot* - In a graph of a time series, one plots the values of the time series x_t at each time t against time $t=1,2,\ldots,n$. Consequently, the point (x_i,y_i) used in the procedure described above is simply replaced by (t,x_t). A smooth through the time series can be used for visually detecting trends, as is shown in Figure 2.1.

2.2.3 Box and Whisker Plot

A box and whisker plot is used to ascertain how observations in a time series are distributed. When dealing with seasonal data, one may wish to know how the data are distributed within each season. Consequently, a separate box and whisker graph can be plotted for each season. Before plotting a box and whisker graph, one may wish to transform the data using the Box-Cox transformation in Equation 2.1.

A box and whisker graph is based upon what is called the 5-number summary (Tukey, 1977, Ch. 2). For a given data set, the 5-number summary consists of the smallest and largest values, the median, and the 0.25 and 0.75 quantiles which are called hinges. When the data are ranked from the smallest to largest value, the first data point is the smallest observation while the last entry is the largest value.

In order to calculate the values of quantiles, it is convenient to employ the operational definition of quantiles given by Chambers et al. (1983). Suppose that the given data represented by x_i for $i = 1,2,\ldots,n$, are ordered from smallest to largest such that the sorted data are denoted by $x_{(i)}$, $i = 1,2,\ldots,n$. If p represents any fraction between 0 and 1, the corresponding quantile is given by $Q(p)$. Whenever p is one of the fractions

$$p_i = (i - 0.5)/n \quad \text{for } i = 1,2,\ldots,n \tag{2.12}$$

$Q(p)$ is assigned the value $x_{(i)}$, which is one of the given data points. For instance, if there were 10 observations, $x_{(2)}$ would have a p_i value of

$$p_2 = (2 - 0.5)/10 = 0.15$$

Hence, the 0.15 quantile, Q(0.15), would be exactly equal to $x_{(2)}$. When p is a fraction f of the way from p_i to p_{i+1}, one must use linear interpolation to estimate $Q(p)$. In particular, for this

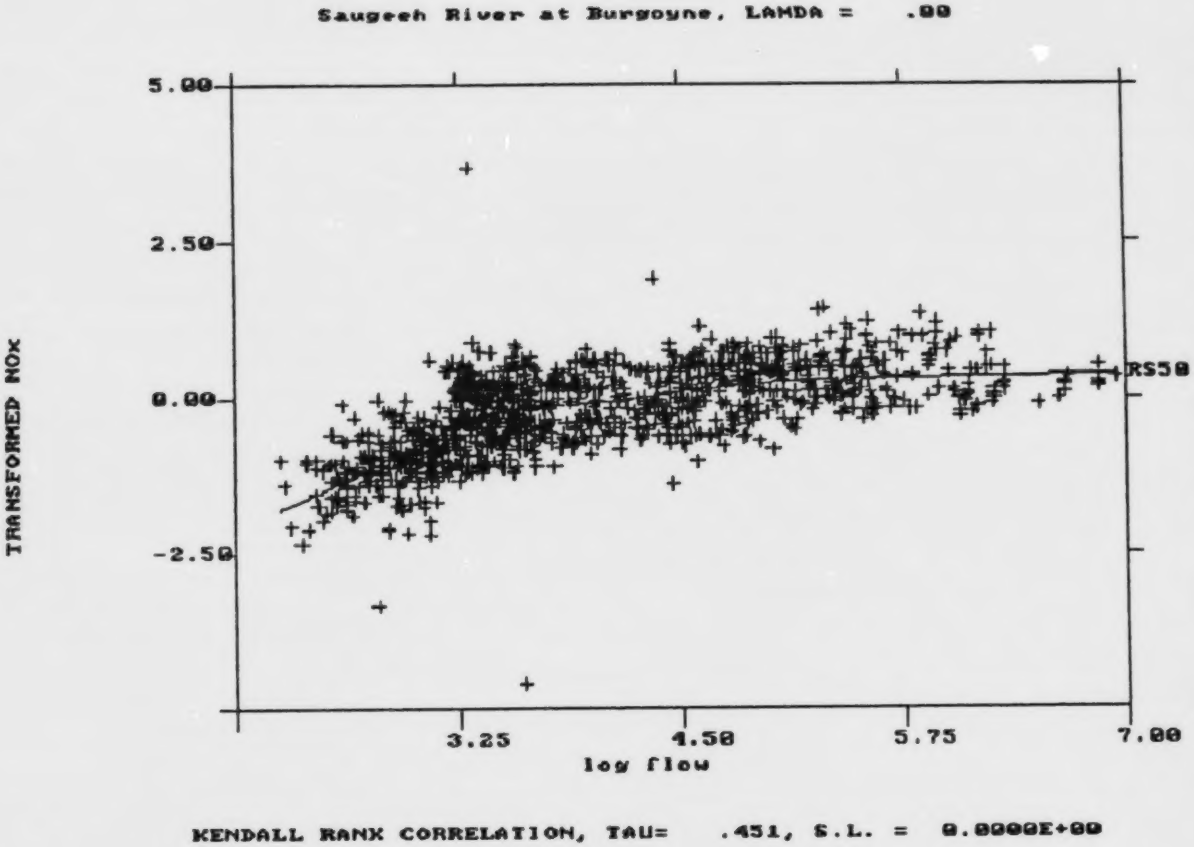

Figure 2.2. Scatter plot of logarithmic nitrates against logarithmic flows for the Saugeen River.

situation the interpolated quantile is calculated as

$$Q(p) = (1 - f)Q(p_i) + fQ(P_{i+1}) \tag{2.13}$$

Returning to the example for which there are 10 data points, the p_i for $x_{(3)}$ and $x_{(4)}$ are determined from Equation 2.12 to be, respectively,

$$p_3 = (3 - 0.5)/10 = 0.25$$

$$p_4 = (4 - 0.5)/10 = 0.35$$

By utilizing Equation 2.12, the quantile for $p = 0.31$ is determined to be

$$
\begin{aligned}
Q(0.31) &= (1 - 0.6)Q(0.25) + 0.6Q(0.35) \\
&= 0.4x_{(3)} + 0.6x_{(4)}
\end{aligned}
$$

A plotting position is a value at which an ordered observation in a sample should be plotted for use on probability paper. In Equation 2.12, p_i stands for the plotting position of the ith ordered value denoted by $x_{(i)}$. The plotting position given by Equation 2.12 is actually a special case of the general plotting position formula written as

$$p_i=(i-\alpha)/(n+1-2\alpha) \tag{2.14}$$

where α is usually assigned values between 0 and 0.5. Detailed discussions regarding probability plotting positions are given by Barnett (1975) and Cunnane (1978) within the statistical and hydrological literature, respectively. As explained by these authors, when $\alpha=0$ in Equation 2.14 one obtains Weibull's formula which is recommended for use with uniformly distributed data. For normal observations, Blom's formula using $\alpha=3/8$ in Equation 2.14 should be employed. Finally, Equation 2.12 is referred to as Hazen's formula and to obtain this one substitutes $\alpha=0.5$ into Equation 2.14.

As noted by Chambers et al. (1983), there are many reasons for choosing p_i to be $(i-0.5)/n$ in Equation 2.12 or, equivalently, $\alpha=0.5$ in Equation 2.14, rather than some other value. One reason is that when the ordered observations are split into two groups exactly on an observation, the use of $(i-0.5)/n$ means that the observation is counted as being half in the lower group and half in the upper group.

Because extrapolation must be done only when necessary and with great care, the formula in Equation 2.13 for calculating $Q(p)$ should not be used outside the range of the data for which p is smaller than $0.5/n$ or larger than $1-0.5/n$. The safest rule for extrapolation is to define $Q(p)=x_{(1)}$ for $p<p_1$ and $Q(p)=x_{(n)}$ for $p>p_n$. According to this rule, $Q(0)$ and $Q(1)$ are assigned values of $x_{(1)}$ and $x_{(n)}$, respectively, which are the smallest and largest observations, respectively, in the given data set.

Equations 2.12 and 2.13 can be used with a data set of length $n \geq 2$. Keeping in mind that the only difference between a percentile and a quantile is that a percentile refers to a percentage of a data set and a quantile refers to a fraction of the data, these equations can also be used to calculate a percentile.

The median, given by $Q(0.5)$, divides the data into two groups of equal size. If n is odd, the median is $x_{((n+1)/2)}$. When n is even, $Q(0.5)$ is calculated using Equation 2.13 as the average of $x_{(n/2)}$ and $x_{(n/2+1)}$, which are the two ordered values closest to the middle.

The lower and upper quantiles which are defined as $Q(0.25)$ and $Q(0.75)$, respectively, are called hinges by Tukey (1977). The distance between the first and third quantile, given by $Q(0.75)-Q(0.25)$ is called the interquartile range. This distance, which can be used to judge the spread of the data, is referred to by Tukey (1977) as the "H spread".

To assist in characterizing extreme values, Tukey (1977) has suggested the following definitions. A step is 1.5 times the H-spread or interquartile range. "Inner fences" are one step outside hinges and "outer fences" are two steps outside hinges. Values between an inner fence and its neighbouring outer fence are called "outside". Values beyond outer fences are "far-out". Assuming that the data follow a given distribution, such as a normal distribution, one can calculate the expected numbers of outside and also far-out values, and compare these to the observed numbers.

When entertaining seasonal data such as monthly or quarterly data, it is instructive to calculate a 5-number summary plus outside and far-out values for each season. A convenient manner in which to display this information is to plot "box-and-whisker" diagrams for each season. The upper and lower end of a rectangle for a given season represent the two hinges and the thick line drawn horizontally with each rectangle is the value of the median. Excluding far-out values, the minimum and maximum values to a particular season are the end points of the lines or "whiskers" attached to the rectangle or "box". The far-out values are indicated by small open squares. The Notches on both sides of a box can be used to ascertain if the median in one month is significantly different from another. In particular, when comparing two months, if the median bar in one month overlaps with the notch in the other, and vice versa, then one can argue that the medians for these two months are not significantly different from one another. When there are not many data points used to determine a box and whisker plot for a given season, any peculiarities in the plot should be cautiously considered.

Another way to investigate extreme values is to calculate far-out values when all of the data across all of the seasons are used. Certainly, if a data point is far-out overall, the scientist should determine whether the measurement is accurate and represents what actually occurred or the observation is really due to measurement error or some other type of mistake. If the validity of a far-out overall or perhaps a far-out seasonal value is in doubt, in certain situations it may be advantageous not to include this data point in subsequent analyses. However, because the general trend analysis methodology developed in this project is robust, far-out values will not alter the overall results.

In addition to detecting far-out values, box and whisker diagrams have other uses. If the data are approximately symmetrical with respect to the median, it may follow a symmetric distribution such as the normal distribution. If there is an obvious lack of symmetry in a box and whisker graph, this may indicate the need for a transformation, such as the Box-Cox transformation in Equation 2.1 to cause the data to be approximately normally distributed. Since, by definition, 25% of the data is contained between the median and a hinge, for normally distributed data the hinge is located 0.68 times the standard deviation from the median or mean. It can also be shown for normal data that inner fences are located a distance of 2.04 standard deviations on either side of the mean and the outer fences are a distance of 3.40 standard deviations from the mean. Consequently, the probability of having a far-out value with normally distribution data, is extremely small. Therefore, using a transformation to normalize a given data set will tend to reduce the number of far-out values.

The box and whisker graphs for the total nitrates in the Saugeen River are displayed in Figure 2.3 for each month of the year (NOXMON). The varying median levels across the months show that the data are seasonal. Notice also for some months that a notch for the mean may extend above an upper hinge or below a lower hinge. In the test given in Section 2.3.7, box and whisker graphs can be used to rank the seasons of the year.

For a given season in a box and whisker diagram, symmetric data would cause the median to lie in the middle of the rectangle and the lengths of the upper and lower whiskers would be about the same. Long upper whiskers for each month, for example, indicate that the data are skewed. A Box-Cox transformation could alleviate this problem.

Box-and-whisker plots can be employed as an important exploratory data analysis tool in intervention studies. If the date of the intervention is known, box-and-whisker diagrams can be constructed for each season for the data before and after the time of intervention. These two graphs can be compared to ascertain for which seasons the intervention has caused noticeable changes. When there are sufficient data, this type of information is crucial for designing a proper intervention model to fit the data at the confirmatory data analysis stage (Hipel and McLeod, 1990).

2.3 Statistical Tests for Trend

2.3.1 Introduction

Statistical tests can be categorized according to parametric and nonparametric. In a parametric test, one must assume an underlying distribution for the data or underlying distribution of the null hypothesis. For example, the normality assumption may be invoked for a parametric test. For the case of a nonparametric test, one does not have to specify a particular underlying distribution for the null hypothesis. Because of this, a nonparametric test is often referred to as a distribution free or distribution independent method. As a matter of fact, some distribution free methods assume that these are parameters in the models which form the bases for the tests whereas other distribution free tests do not involve any parameters either directly or indirectly in the tests. Although the term nonparametric should be confined to describing distribution free tests for which there are no parameters, in practice it has been interpreted as standing for the set of all distribution free methods.

Nonparametric tests were adopted and developed for use in environmental impact assessment because the statistical characteristics of messy environmental data make it difficult or unwise to use many of the parametric methods. In response to the need for nonparametric procedures, authors such as Lettenmaier (1976), Hirsch et al. (1982), Hirsch and Slack (1984), Van Belle and Hughes (1984), El-Shaarawi and Kwiatowski (1986), as well as authors in the monograph edited by Hipel (1988) have made significant contributions to the development and application of nonparametric models in water resources.

Parametric models and tests have been employed for addressing problems in water resources for a long time. To see how parametric procedures such as regression analysis and time series analysis are used in water resources and environmental engineering, the reader may wish to refer to water resources textbooks such as the ones by Salas et al. (1980), Loucks et al.

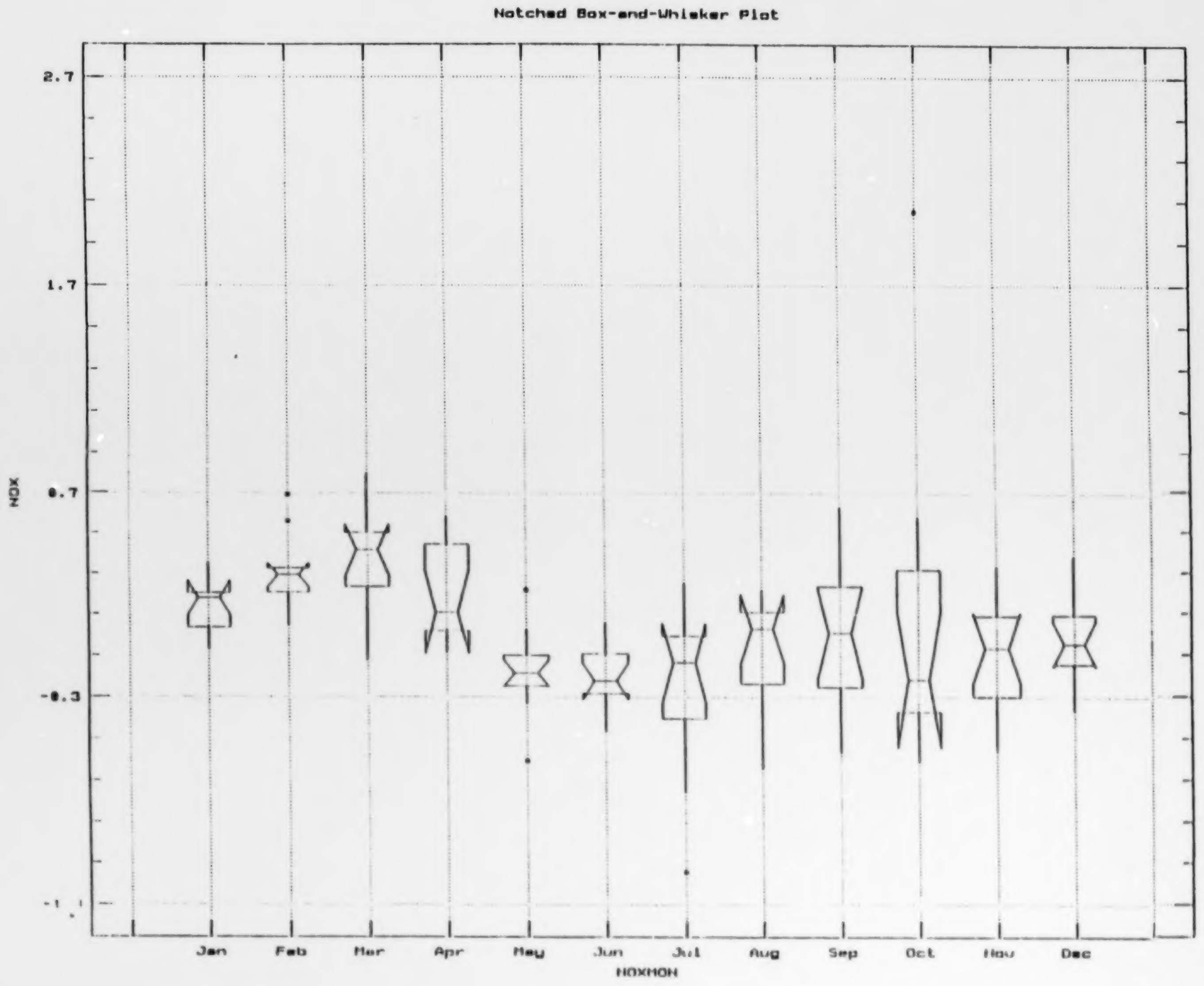

Figure 2.3. Box and whisker graph for the logarithmic monthly total nitrates in the Saugeen River.

(1981) and Hipel and McLeod (1990).

In the general methodology for trend analysis presented in Section 3, both parametric and nonparametric procedures are employed. The specific statistical methods used at different stages in the methodology for trend detection are now described.

2.3.2 Mann-Kendall Test

Mann (1945) presented a nonparametric test for randomness against time which constitutes a particular application of Kendall's test for correlation (Kendall, 1975) commonly known as the Mann-Kendall or the Kendall t statistic. Letting $x_1, x_2, \cdots, x_n$, be a sequence of measurements over time, Mann (1945) proposed to test the null hypothesis, H_0, that the data come from a population where the random variables are independent and identically distributed. The alternative hypothesis, H_1, is the data follow a monotonic trend over time. Under H_0, the Mann-Kendall test statistic is

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \tag{2.15}$$

where

$$sgn(x) = \begin{cases} +1 & x > 0 \\ 0 & x = 0 \\ -1 & x < 0 \end{cases}$$

Kendall (1975), showed that S is asymptotically normally distributed and gave the mean and variance of S, for the situation where there may be ties in the x values, as

$$E[S] = 0$$

$$Var[S] = \left\{ n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j - 1)(2t_j + 5) \right\} / 18 \tag{2.16}$$

where p is the number of tied groups in the data set and t_j is the number of data points in the jth tied group.

When using Equation 2.15, a positive value of S indicates there is an upward trend where the observations increase with time. On the other hand, a negative value of S means that there is a downward trend. Because it is known that S is asymptotically normally distributed and has a mean of zero and variance given by Equation 2.16, one can check whether or not an upward or downward trend is significantly different from zero. If the S is significantly different from zero, based upon the available information H_0 can be rejected at a chosen significance level and the presence of a monotonic trend, H_1, can be accepted.

A problem which can arise when using the Mann-Kendall trend test is how to summarize information when there are several values for a given year. Van Belle and Hughes (1984, p. 135) suggest four possible approaches for accomplishing this. A simple procedure, for example, is to simply replace the set of values by the median or mean before calculating the test statistic. An alternative to calculating a mean or median within a given year, is to consider these values as tied in the time index and then to compute the test statistic along with a modified variance. Van Bell and Hughes (1984, p. 135) present the formulae for carrying this out.

The exact distribution of S for $n \geq 10$ was derived by both Mann (1945) and Kendall (1975). They showed that even for small values of n, the normality approximation is good provided one employs the standard normal variate Z given by

$$Z = \begin{cases} \dfrac{S-1}{[Var(S)]^{1/2}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{[Var(S)]^{1/2}} & \text{if } S < 0 \end{cases} \qquad (2.17)$$

The statistic S in Equation 2.15 is a count of the number of times x_j exceeds x_k, for $j>k$, more than x_k exceeds x_j. The maximum possible value of S occurs when $x_1<x_2< \cdots <x_n$. Let this number be called D. A statistic which is closely related to S in Equation 2.15 is Kendall's tau defined by

$$\tau = \frac{S}{D} \qquad (2.18)$$

where

$$D = \left[\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{j=1}^{p} t_j(t_j-1)\right]^{1/2} \left[\frac{1}{2}n(n-1)\right]^{1/2}$$

When there are no ties in the data, Equation 2.18, collapses to

$$\tau = \frac{S}{\frac{1}{2}n(n-1)} = \frac{S}{\binom{n}{2}} \qquad (2.19)$$

Due to the relationship between τ and S in Equation 2.18, the distribution of τ can be easily obtained from the distribution of S. If there are no ties in the data, the algorithm of Best and Gipps (1974) can be employed to obtain the exact upper tail probabilities of Kendall's tau, or equivalently S, for $n \geq 2$.

Because the distribution of τ, or equivalently S is known, for an estimated value of τ or S one can calculate the corresponding significance level (SL). For example, in Figure 2.1 the estimated value of τ for the flows of the Saugeen River is determined using Equation 2.18 to be 0.284. The SL for this value of τ is calculated to be very close to zero. Consequently, based upon the given data one can reject the null hypothesis that the data come from a population for which the random variables are independent and identically distributed and accept the alternative hypothesis that the data follow a monotonic trend over time. From the RLWRS in Figure 2.1, one can see that there is an increasing trend in the data, as is also confirmed by the positive value of τ. Nonetheless, because of the apparent seasonality in the data, one may also wish to employ a trend test that takes into account seasonality.

2.3.3 Kendall Rank Correlation Test

The Kendall rank correlation test (Kendall, 1975) is a nonparametric test for checking if two series are independent of one another. The null hypothesis, H_0, is that the two series are independent of each other while the alternative hypothesis, H_1, is they are not independent.

Suppose that the data consist of a bivariate random sample if size n, (x_i,y_i), for $i=1,2,\ldots,n$. Two observations are concordant if both members of one bivariate observation are larger than their respective members of the other observation. For example, the two bivariate observations (3.2,9.6) and (4.7,11.2) are concordant. Out of the $\binom{n}{2}$ total possible pairs, let N_c denote the number of concordant pairs of observations. A pair of bivariate observations, such as (5.2,8.6) and (4.3,12.4), is discordant if it is not concordant. Let N_d be the total number of discordant pairs. Under H_0, the test statistic for the Kendall rank correlation test is

$$\tau=\frac{N_c-N_d}{\frac{1}{2}n(n-1)} \tag{2.20}$$

If all pairs are concordant, the two series are perfectly correlated and $\tau=1$. For the case of total discordance, $\tau=-1$. Consequently, τ varies between -1 and +1. Because τ is asymptotically normally distributed and its distribution can be tabulated exactly for small n, one can determine the SL for a computed value of τ. If the calculated τ is greater than or less than 0.05, one can accept or reject, respectively, the null hypothesis.

Notice that the symbol for tau used in Equation 2.20 is identical to that used in Equation 2.19. This is because the test statistic given in Equation 2.19 for the Mann-Kendall test is a special case of the test statistic for the Kendall rank correlation test in Equation 2.20. To obtain Equation 2.19 from Equation 2.20, simply replace (x_i,y_i) by (t,x_t) for which time $t=1,2,\ldots,n$, and x_t consists of $x_1,x_2,\ldots,x_n$.

An example of the Kendall rank correlation test is presented in Figure 2.2 where logarithmic flows are plotted against logarithmic nitrates for the Saugeen River at Burgoyne. The calculated value of τ has a value of 0.451 and a corresponding SL of almost zero. Because of the very small SL, one can, based upon the data, reject the null hypothesis that the series are independent of each other and accept the alternative hypothesis that the two series are not independent.

2.3.4 Spearman's Rho Test

In 1904, Spearman introduced a nonparametric coefficient of rank correlation denoted as ρ_{XY} which is based upon the squared differences of ranks between two variables. Spearman's rho can be employed as a nonparametric test to check whether or not there is significant correlation between two variables X and Y.

Let the sample consist of a bivariate sample (x_i,y_i) for $i=1,2,\ldots,n$, where n is the sample size. Suppose that the values of the X variable are ranked from smallest to largest such that the rank of the smallest value is one and that of the largest value is n. Let $R_i^{(X)}$ represent the rank of the X variable measured at time i. Likewise, the values of the Y variable can be ranked and $R_i^{(Y)}$ can represent the value of the rank for the Y variable at time i. The sum of the squared differences of the ranks is

$$S(d^2)=D^2=\sum_{i=1}^{n}(R_i^{(X)}-R_i^{(Y)})^2 \tag{2.21}$$

Spearman's rho is then defined for the case where there are no ties in X and Y as

$$\rho_{XY}=1-\frac{6S(d^2)}{n^3-n} \tag{2.22}$$

When the two rankings for X and Y are identical $\rho_{XY}=1$ whereas $\rho_{XY}=-1$ when the rankings of X and Y are in reverse order.

If some values of X or Y are tied, these values are simply assigned the average of the ranks to which they would have been assigned. Let p be the number of tied groups in the X data set where t_j is the number of data points in the jth tied group. Likewise, let q be the number of tied groups in the Y sequence where u_j is the number of observations in the jth tied group. Then the formula for calculating ρ_{xy} when there are ties in either or both time series is (Kendall, 1975, p. 38, Equation 3.8)

$$\rho_{XY}=\frac{\frac{1}{6}(n^3-n)-S(d^2)-\frac{1}{12}\sum_{j=1}^{p}(t_j^3-t_j)-\frac{1}{12}\sum_{j=1}^{q}(u_j^3-u_j)}{\left[\left\{\frac{1}{6}(n^3-n)-\frac{1}{6}\sum_{j=1}^{p}(t_j^3-t_j)\right\}\left\{\frac{1}{6}(n^3-n)-\frac{1}{6}\sum_{j=1}^{q}(u_j^3-u_j)\right\}\right]^{1/2}} \tag{2.23}$$

When using ρ_{XY} in a statistical test to check for the absence or presence of correlation, the null hypothesis, H_0, is that there is no correlation, For large samples, ρ_{XY} is distributed as $N\left(0,\frac{1}{n-1}\right)$ where n is the sample size. The alternative hypothesis, H_1, is that there is correlation between the X and Y variables.

By letting one of the variables represent time, Spearman's rho test can be interpreted as a trend test. In particular, replace (x_i,y_i) by (t,x_t) for which $t=1,2,\ldots,n$, and x_t consists of $x_1,x_2,\ldots,x_n$. Equations 2.21 to 2.23 can then be employed to calculate a statistic for use in a trend test. If, for example, the estimated value of ρ_{XY} is significantly different from zero, then one can argue that time and the X variable are significantly correlated, which in turn means there is a trend.

As example of applying the ordinary Spearman rho trend test, consider the results for the NO_x data for the Saugeen River listed in the appendix. For the flow adjusted NO_x data (the procedure for calculating flow adjusted data is explained in Section 3), the value of ρ_{XY} is 0.542 and the SL is almost zero. Hence, the significantly large positive value of ρ_{xy} indicates an increasing trend with time.

2.3.5 Seasonal Mann-Kendall Test

Hirsch et al. (1982) defined a multivariate extension of the Mann-Kendall statistics of Section 2.3.2 for use with seasonal data, and, as noted by Van Belle and Hughes (1984), their test possesses some similarities to tests proposed by Jonckheere (1954) and Page (1963). Although the statistic of Hirsch et al. (1982), is valid for use with data where there may be missing values (see discussion in Section 2.1 on missing values) and also ties, assume for the present that the time series X consists of a complete record sampled over n years where there are m seasons per year such that X is given by

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ . & . & & . \\ . & . & & . \\ . & . & & . \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix}$$

The null hypothesis H_0 is that for each of the m seasons the n observations are independent and identically distributed while the alternative hypothesis is there is a monotonic trend. Let the matrix of ranks be denoted by

$$R = \begin{bmatrix} R_{11} & R_{12} & \cdots & R_{1m} \\ R_{21} & R_{22} & \cdots & R_{2m} \\ . & . & & . \\ . & . & & . \\ . & . & & . \\ R_{n1} & R_{n2} & \cdots & R_{nm} \end{bmatrix}$$

where the n observations for each season or column in R are ranked among themselves. Hence, the rank of x_{jg}, which is the jth data point in the gth season, is

$$R_{jg} = [n + 1 + \sum_{i=1}^{n} sgn(x_{jg} - x_{ig})]/2 \tag{2.24}$$

and each column of R is a permutation of $(1,2, \cdots ,n)$. The Mann-Kendall test statistic for the gth season is (Hirsch et al., 1982)

$$S_g = \sum_{i=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_{jg} - x_{ig}) \quad g = 1,2, \cdots ,m \tag{2.25}$$

Similar to the situation of S in Equation 2.15, S_g is asymptotically normally distributed where

$$E[S_g] = 0$$

$$Var[S_g] = \sigma_g^2 = n(n-1)(2n+5)/18 \tag{2.26}$$

Kendall's tau statistic can be defined for the gth season as

$$\tau_g = \frac{S_g}{\frac{1}{2}n(n-1)} = \frac{S_g}{\binom{n}{2}} \tag{2.27}$$

Because τ_g is simply a multiple of S_g, the distribution of τ_g can be obtained from the distribution of S_g. In particular, τ_g is asymptotically normally distributed where

$$E[\tau_g] = 0$$

$$Var[\tau_g] = \frac{1}{\left[\frac{1}{2}n(n-1)\right]^2} \left[\frac{n(n-1)(2n+5)}{18}\right] \tag{2.28}$$

Since it is arithmetically more convenient to deal with S_g rather than τ_g and also Hirsch et al. (1982) use mainly S_g rather than τ_g in their research, the statistic S_g is utilized in the rest of this section.

Following Hirsch et al. (1982), the seasonal Mann-Kendall test statistic is

$$S' = \sum_{g=1}^{m} S_g \tag{2.29}$$

which is asymptotically normally distributed where

$$E[S'] = 0$$

$$Var[S'] = \sum_{g=1}^{m} \sigma_g^2 + \sum_{\substack{g,h \\ g \neq h}} \sigma_{gh} \tag{2.30}$$

Using Equation 2.26, $\sigma_g^2 = Var[S_g]$ can be calculated and $\sigma_{gh} = cov(S_g S_h)$. For the situation where each season is independent of each of the other seasons, the second summation in

Equation 2.30 is zero and

$$Var[S'] = \sum_{g=1}^{m} \sigma_g^2 \tag{2.31}$$

As is done in Equation 2.17 for the Mann-Kendall test, for $n \le 10$ the standard normal deviate Z' should be calculated as

$$Z' = \begin{cases} \dfrac{S'-1}{[Var(S')]^{1/2}} & \text{if } S' > 0 \\ 0 & \text{if } S' = 0 \\ \dfrac{S'+1}{[Var(S')]^{1/2}} & \text{if } S' < 0 \end{cases} \tag{2.32}$$

When utilizing Equation 2.32, Hirsch et al. (1982) demonstrate that the normal approximation is quite accurate even for data as small as $n = 2$ and $m = 12$.

To handle *missing values*, $sgn(x_{jg} - x_{ig})$ is defined to be zero if either x_{jg} or x_{ig} is missing. Letting n_g be the number of nonmissing observations for season g, Equation 2.24 is modified as

$$R_{jg} = [n_g + 1 + \sum_{i=1}^{n} sgn(x_{jg} - x_{ig})]/2 \tag{2.33}$$

Consequently, the ranks of the known observations remain unchanged and each missing observation is assigned the average or midrank $(n_g + 1)/2$. As is the case when there are no missing observations, Equation 2.25 is used to calculate S_g and following Equation 2.26 the variance of S_g is determined using

$$\sigma_g^2 = n_g(n_g - 1)(2n_g + 5)/18 \tag{2.34}$$

S' and its variance are determined using Equations 2.29 and 2.30, respectively, where each σ_{gh} is zero.

For censored water quality time series where some data are reported to be less than a *limit of detection*, arbitrarily fix the affected data at some constant value which is less than the limit of detection. Because nonparametric tests are based upon ranks instead of magnitudes, all censored values are interpreted as sharing the same rank which is less than the rank of all uncensored observations. Additionally, this means that handling censored data is equivalent to dealing with *ties*. Assuming, for the moment, that there are no missing values, the ranked data containing ties can be calculated using Equation 2.24, which automatically assigns to each of t tied values the average of the next t ranks. Following this, S_g can be determined utilizing Equation 2.25 where, similar to the situation in Equation 2.16, the variance is

$$Var[S_g] = \sigma_g^2 = [n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j - 1)(2t_j + 5)]/18 \tag{2.35}$$

where n is the number of years of data, p is the number of tied groups for the data x_{ig},

$i = 1,2, \cdots, n$, in season g, and t_j is the size of the jth tied group. The seasonal Mann-Kendall statistic is calculated using Equation 2.25 while its variance is determined by utilizing Equation 2.30 where all the σ_{gh} are zero. When there are both tied data (due to "tied" censored data and ties of actual observations) and missing values, the modifications described in this and the previous paragraph must be combined.

To handle data when there are several values for a given season and a specified year, the reader can refer to the discussion in Section 2.3.2. A simple approach is to replace the set of values by the median or mean before calculating the test statistic.

In practice, one should examine carefully how S_g in Equation 2.25 behaves for each season. Only if the same type of trend, such as an upward trend, is detected in each season, will the overall seasonal Mann-Kendall test in Equation 2.29 have any meaning. In other words, S' should only be calculated for a group of seasons which are expected to behave in a certain manner where hypothesis testing is done separately for this group.

When employing Equation 2.31 to estimate the variance of the overall seasonal Mann-Kendall statistic, it is assumed that the individual seasonal test statistics are independent of one another. However, in some practical applications this may not be the case. For instance, when dealing with average monthly phosphorus levels in a river, the phosphorus observations in one month may be significantly correlated with values in the preceding one or more months. This means that in order to employ the seasonal Mann-Kendall tests in Equations 2.25 and 2.29, one must be able to estimate all the σ_{gh} in Equation 2.30.

Based upon research by Dietz and Killeen (1981), Hirsch and Slack (1984) present a method for estimating σ_{gh} in Equation 2.30. Lettenmaier (1988) develops the covariance-eigenvalue method for handling correlation among seasons and uses simulation experiments to compare the power of his seasonal trend test to those of Hirsch and Slack (1984) as well as Dietz and Killeen (1981). He demonstrates that his covariance-eigenvalue method performs much better than the technique of Dietz and Killeen (1981) and nearly as well as the method of Hirsch and Slack (1984).

The seasonal Mann-Kendall test described in this section should only be used when the data are seasonal. Simulation experiments demonstrate that if there is no seasonality the Mann-Kendall test of Section 2.3.2 is much more powerful to use for trend detection than the seasonal Mann-Kendall test of this section.

To demonstrate the use of the seasonal Mann-Kendall test, consider the flow adjusted NO_x data for the Saugeen River presented in the appendix. The values of the seasonal Mann-Kendall statistic and variance using Equations 2.29 and 2.31, are 314 and 2147, respectively. Because the test statistic is positive, there is an increasing trend over time while the SL of almost zero indicates that this trend is significant.

2.3.6 Kruskal-Wallis Test

The Kruskal-Wallis test constitutes a nonparametric approach for checking whether or not the distributions or means across k samples are the same (Kruskal and Wallis, 1952). In contrast to the normality assumption for the one way analysis of variance (ANOVA), the k population distributions are only assumed to be identical for the Kruskal-Wallis test. However, as is the case for the one way ANOVA, the observations are assumed to be independent of another.

Suppose that there are k samples of sizes n_i, $i = 1,2, \cdots ,k$, having a combined sample size n defined by

$$\sum_{i=1}^{k} n_i = n \qquad (2.36)$$

Let x_{ij} stand for the jth value in the ith sample so that $i = 1,2, \cdots ,k$, and $j = 1,2, \cdots ,n_i$. Denote the ith random sample of size n_i by $x_{i1},x_{i2}, \cdots ,x_{in_i}$. Rank the n observations from 1 to n where ranks 1 and n are assigned to the smallest and largest observations, respectively. For tied observations, assign each observation the average of the ranks that would be assigned to the observations. Let $R(x_{ij})$ represent the rank assigned to x_{ij}. For the ith sample, the sum of the ranks is given by

$$R_i = \sum_{j=1}^{n_i} R(x_{ij}) \quad i = 1,2, \cdots ,k \qquad (2.37)$$

The null hypothesis is that all of the k population distribution functions are identical. This implies that the k means are the same. The alternative hypothesis is that at least one of the populations yields larger observations than at least one of the other populations. Therefore, the k populations do not all have identical means.

The test statistic for the Kruskal-Wallis test is

$$T = \frac{12}{n(n+1)} \sum_{i=1}^{k} \frac{[R_i - (1/2)n(n+1)]^2}{n_i} \qquad (2.38)$$

where n and R_i are defined in Equations 2.36 and 2.37, respectively. The exact distribution of T is known (Kruskal and Wallis, 1952) and for small samples (say $k = 3$ and $n_i \le 5$, $i = 1,2,3$) one can obtain the SL for the observed T from tables. For larger samples, T is approximately χ^2 distributed on $k - 1$ degrees of freedom.

Compared to the usual parametric F test used in the one way ANOVA, the Kruskal-Wallis test is very efficient. For example, when the assumptions of the F test are satisfied, the asymptotic relative efficiency of the Kruskal-Wallis test compared to the F test is 0.955. A detailed description of the Kruskal-Wallis test is presented by Conover (1971, pp. 256-263).

The Kruskal-Wallis test can be employed for testing whether or not a time series is seasonal. To apply the test, the data contained within a given season is considered as one separate sample. For example, when dealing with monthly observations, each of the twelve samples would consist of the monthly data from that month across all of the years. A significantly large value of the Kruskal-Wallis statistic would mean that the means and perhaps other distributional parameters vary across the seasons. On the other hand, if the Kruskal-Wallis statistic were not significant, this would mean that the data are not seasonal.

In the appendix, the results for the Kruskal-Wallis test for monthly seasonality are presented for the flow adjusted NO_x data for the Saugeen River. Because the test statistic of 47.52 has a SL of almost zero the data are seasonal. In the table, the average ranks for each season are presented so that one can then rank the seasons from smallest to largest. Notice that some of the seasons have about the same average rank. As noted in Section 2.2.3 and shown in Figure 2.3, box and whisker graphs can be used to rank seasons according to seasonal medians.

2.3.7 Spearman Partial Rank Correlation Test

Description

When examining a dependence between two variables X and Y, the question arises as to whether or not the correlation between X and Y is due to the correlation of each variable with a third variable Z. For example, one may wish to ascertain if an apparent trend in a water quality variable, as reflected by the correlation of the water quality variable over time, is independent of seasonality. Therefore, one would like to eliminate or "partial out" the effects of seasonality when testing for a trend in the water quality variable over time.

The purpose of the Spearman partial rank correlation test presented in this section is to determine the correlation between variables X and Y after the effects of Z upon X and Y separately are taken into account and are, therefore, removed. The notation used to represent this type of partial correlation is $corr(XY/Z)$ or $\rho_{XY.Z}$.

Let the sample consist of a trivariate sample (x_i,y_i,z_i) for $i=1,2,\ldots,n$, where n is the sample size. As is also done for the Spearman's rho test in Section 2.3.4, suppose that the values of the X variable are ranked from smallest to largest such that the rank of the smallest value is one and that of the largest value is n. Let $R_i^{(X)}$ represent the rank of the X variable at time i. Likewise, the values of the Y and Z variables can be ranked separately to produce $R_i^{(Y)}$ and $R_i^{(Z)}$, respectively.

The test statistic for the Spearman partial rank correlation test is calculated using

$$\rho_{XY.Z}=\frac{\rho_{XY}-\rho_{XZ}\rho_{YZ}}{(1-\rho_{XZ}^2)^{1/2}(1-\rho_{YZ}^2)^{1/2}} \tag{2.39}$$

Each rho term on the right hand side of Equation 2.39 is calculated using Equation 2.22 when there are no ties in any variable or Equation 2.23 where there are ties.

Under the null hypothesis, there is no correlation between X and Y when the effects of Z are partialled out. To test the null hypothesis that $E(\rho_{XY.Z})=0$, one calculates

$$t=\frac{(n-2)^{1/2}\rho_{XY.Z}}{(1-\rho_{XY.Z}^{2})^{1/2}} \tag{2.40}$$

where $\rho_{XY.Z}$ is defined in Equation 2.39. Under H_o, t follows a student t distribution on $(n-2)$ degrees of freedom (Pitman's approximation), which is the same as ρ_{XY} in Equations 2.22 and 2.23, respectively. The alternative hypothesis, H_1, is there is correlation between X and Y, after accounting for the influence of Z separately upon X and Y. If, for example, the SL for the test statistic were calculated to be very small and less than 0.05, one could reject the null hypothesis that X and Y are not correlated when Z is partialled out. When the X, Y and Z variables represent a given water quality time series, time and seasonality, respectively, then a significantly large value of the Spearman partial rank correlation coefficient means that there is a trend in the series over time when seasonality is removed.

The partial Spearman correlation test can be used with data for which there are missing values, ties and one level of censoring, either on the left or right. If the data are multiply censored, one can use the expected rank vector approach of Hughes and Millard (1988) before applying the test.

Application

To explain how the partial Spearman correlation test can be applied in practice, once again consider the flow adjusted NO_x data for the Saugeen River. Suppose that one wishes to ascertain whether or not there is a trend in the series after seasonality is partialled out. The values of the X variable, as represented by the X_t series, are the flow adjusted NO_x series. The Y_t series is simply the ordering of the X_t series according to time and, therefore, $Y_t=t$, for $t=1,2,\ldots,n$. To obtain the Z_t series for representing seasonality, one can use the results of the Kruskall-Wallis test for seasonality of Section 2.3.6 or any other appropriate test results or graphical output. As part of the results for the Kruskall-Wallis test, one can get the average rank for each season. In the Appendix, the average rank for each month of the flow adjusted data is listed along with the rank for each month. After following the procedure for calculating the Spearman partial rank correlation coefficient in Equation 2.39, one obtains a value of 0.572 and a SL of close to zero. Consequently, when the effects of seasonality are removed, there is a significant trend in the flow adjusted NO_x data.

Besides checking for trend after removing seasonality, the Spearman partial rank correlation test can be used for other purposes. For example, it can be extended to take into account correlation when testing for the presence of a trend.

Comparison to the Seasonal Mann-Kendall Test

Besides the Spearman partial rank correlation test of this section, recall that the seasonal Mann-Kendall test of Section 2.3.5 can also be used to check for trend in a seasonal time series. However, the Spearman partial rank correlation test has many advantages over the seasonal Mann-Kendall test including:

1. simulation experiments demonstrate that it has more power,
2. it is more flexible and can be extended, for example, to take into account correlation,
3. and it provides an estimate of the magnitude of the trend through the coefficient in Equation 2.39.

For example, when one is using the Spearman partial rank correlation coefficient, to check for a trend in a variable X over time when seasonality is partialled out (see explanation in last subsection), longer positive and negative values indicate bigger upward and downward trends over time, respectively.

Kendall Partial Rank Correlation Coefficient

Another coefficient for determining the correlation between two variables X and Y when the effects of Z upon each of these variables is taken into account is the Kendall partial rank correlation coefficient (Kendall, 1975, Ch. 8). However, because of the way the statistic is defined, it possesses some serious theoretical drawbacks. The end result is the distribution of the statistic is not known so that it cannot be used in hypothesis testing.

Before describing in more detail specific disadvantages, some notation is required. Let τ_{XY}, τ_{ZY} and τ_{XZ} represent the Kendall rank correlation coefficient between X and Y, Z and Y and X and Z, respectively. Also, let $\tau_{XY.Z}$ be the Kendall partial rank correlation statistic to determine the rank correlation between X and Y, taking into account the effects of Z upon these variables. Finally, let $\rho'_{XY.Z}$ be the Pearson partial rank correlation coefficient. For equations defining these statistics, the reader can refer to Kendall (1975).

The disadvantages of using the Kendall partial rank correlation coefficient include:

1. If the X, Y and Z variables are multivariate normally distributed and the Pearson partial rank correlation coefficient $\rho'_{XY.Z}=0$, it can be shown using simulation and also from the relationship

$$E(\tau_{XY.Z})=\frac{2}{\pi}\sin^{-1}\rho'_{XY.Z} \tag{2.41}$$

   that $\tau_{XY.Z}$ is different from zero. This does not occur with the Spearman partial rank correlation coefficient.
2. The variance of the estimate for $\tau_{XY.Z}$ depends on τ_{XY}, τ_{ZY} and τ_{XZ}. The analogous undesirable property does not hold for the Pearson or Spearman partial rank correlation coefficient.
3. On intuitive grounds, it appears that the Kendall partial rank correlation coefficient does not eliminate in a linear way the effects of Z.

Because of the foregoing disadvantages, the Kendall partial rank correlation coefficient is not used in this study.

2.4 Summary

A range of informative graphical methods and statistical tests are available for use as exploratory and confirmatory data analysis tools when carrying out an environmental impact assessment study. For example, the robust locally weighted regression smooth of Section 2.2.2 is an informative visual device for detecting trends in graphs of time series. A particularly powerful and useful test for confirming the presence of a trend and obtaining an estimate of its magnitude is the Spearman partial rank correlation test of Section 2.3.7.

Other graphical methods and statistical tests may also be advisable to use in a given trend assessment study. When appropriate, practitioners are, of course, encouraged to use them. For instance, when step trends are present, one may wish to consider using tests proposed by Hirsch (1988) and others. However, the statistical procedures given in Sections 2.2 and 2.3 were found to be especially useful for analyzing water quality data in Southern Ontario in order to produce the extensive trend assessment results tabulated in the Appendix.

To apply the statistical techniques of this Section to water quality and quantity data, a systematic methodology should be followed. Montgomery and Reckhow (1984), Berryman et al. (1988), as well as other authors, have suggested overall procedures for analyzing environmental data. However, based upon an understanding of both the statistical and physical characteristics of the time series which were examined in this study, a flexible approach was required for properly examining water quality data in Southern Ontario and elsewhere. Consequently, in Section 3 a new methodology is presented for carrying out an effective trend analysis study of water quality time series.

3. TREND ANALYSIS METHODOLOGY

3.1 Introduction

The purpose of this section is to present a general methodology for analyzing trends in water quality time series measured in rivers. When checking for the presence of a trend in a water quality time series, the methodology properly takes into account the effects of riverflows and seasonality upon the water quality observations. Furthermore, the methodology can be used with "messy" water quality data (see Section 2.1) which may possess undesirable characteristics such as having outliers, non-normality and missing value.

To design the steps presented in the methodology, the authors examined a wide variety of water quality time series measured in the Saugeen and Grand Rivers in Southern Ontario. Based upon the many types of trend analysis problems that arose when analyzing the data, a systematic procedure for studying the time series was developed. Because unforeseen problems were discovered as different kinds of water quality data were analyzed, the trend analysis algorithm was built and improved in an iterative fashion. The final product is a comprehensive and flexible trend analysis methodology for carrying out systematic trend studies of water quality time series.

Within the steps in the methodology, specific graphical, parametric and nonparametric techniques described in Section 2 are utilized. Although the authors found these techniques to be sufficient for handling all the trend analysis problems they encountered, practitioners and researchers may wish to employ additional specific methods at certain steps in the algorithm. For instance, when looking for basic characteristics of the data by examining graphs of the data, some people may wish to use graphical methods beyond those presented in Section 2.2. Whatever the case, the main steps in the algorithm will remain the same.

3.2 Methodology Description

The methodology given below is valid for use with messy water quality series measured in rivers. In the description, it is assumed that one is ultimately wishing to detect trends at the monthly level. Nonetheless, the methodology can be easily converted for use with other seasonal levels such as quarter-yearly or weekly. To explain the procedure, the NO_x and riverflow data for the Saugeen River are employed. In Section 4, the trend analysis methodology of this section is applied to a wide variety of water quality time series measured in the Saugeen and Grand Rivers in Southern Ontario. The main findings are summarized in Section 4 while the detailed results are given in the Appendix.

The overall trend analysis study is divided into the two main categories of Graphical Studies and Trend Tests. These two groupings reflect the idea of exploratory and confirmatory data analysis referred to in Section 2.1. Within the category of Graphical Studies, the following three versions of the water quality series are examined first for trends:

1. *Raw or adjusted water quality time series*: The given series may be transformed by the Box-Cox transformation in Equation 2.1 in an attempt to make a non-normal time series become approximately normally distributed (see discussion in Section 2.1).
2. *Flow-adjusted water quality time series*: This is the time series for which affects of flow upon water quality are removed, as explained in detail below. As mentioned in Section 1 just after Equation 1.1, in certain situations one may wish to use a covariate series other than flow to adjust the water quality series. If this is the case, replace the word flow by the name of the covariate in the general methodology described in this section.
3. *Detrended-flow-adjusted water quality data*: After removing trends from the water quantity time series, the affects of flow upon the water quality time series are eliminated in order to produce the detrended-flow-adjusted water data.

Following this, the three average monthly versions of the above three kinds of data listed below are studied using graphical procedures. As noted at the start of Section 3.2, one can easily use a seasonal time scale other than monthly. If this is required, replace the word monthly by the designated seasonal category in the description of the methodology.

4. *Mean monthly unadjusted water quality time series.*
5. *Mean monthly flow-adjusted water quality time series.*
6. *Mean monthly detrended-flow-adjusted water quality time.*

The manner in which these series are calculated is explained below. The main graphical procedure used to examine the six types of water quality data are a trace or time series plot (Sections 2.2.1 and 2.2.2) along with a smoothed curve (called RLWRS in Section 2.2.2) through the plotted data. Finally, under the category of Trend tests, the above three types of monthly water quality data are analyzed using trend tests from Section 2.3. Of particular importance is the Spearman partial rank correlation test described in Section 2.3.7 which works extremely well with seasonal data.

The overall trend analysis methodology is summarized in Table 3.1. Specific details are presented in Table 3.2 for carrying out the Spearman partial rank correlation mentioned under d in Table 3.1. The steps in the methodology are now explained in detail using the total nitrate (i.e., NO_x) data measured in the Saugeen River at Burgoyne.

3.2.1 Graphical Trend Studies

Given Data

1. Unadjusted water quality time series: As in Table 3.1, the first step is to examine a trace along with a RLWRS of the given unadjusted data or the data transformed by a Box-cox transformation in Equation 2.1. A common transformation is to take natural logarithms of the data (i.e., $\lambda=0$ in Equation 2.1). A graph of the logarithmic total nitrates (NO_x) for the Saugeen River is displayed in Figure 3.1, as well as in Figure 2.1. One can easily see the increasing trend over time followed by the RLWRS. Additionally, the results of the Mann-Kendall test at the bottom of the graph also confirms the presence of a trend. However, the SL may not be meaningful because of the high degree of correlation in the data caused by frequent sampling at particular time periods, especially from 1976 to 1978. Moreover, there is also strong seasonality in this data which the Mann-Kendall test cannot properly take into account.

2. Flow-adjusted water quality time series: The question arises as to whether or not a given water quality variable is dependent upon flow. Figure 3.2 and also Figure 2.2 display scatter plots of logarithmic NO_x series against logarithmic flows. Each flow value is plotted for exactly the same time at which the corresponding NO_x observation is made. As shown by the RLWRS, there is an obvious dependency between NO_x and flow. The value of the Kendall rank correlation test statistic (Section 2.3.3) listed at the bottom of Figure 3.2 for the data plotted in this figure, shown in Figure 3.2 is also significantly large and, therefore, confirms this finding.

Each sample flow value in Figures 3.2 and 2.2 is the average daily value for the day on which the corresponding NO_x value was collected. For relatively large rivers such as the Saugeen and Grand, the discrepancy between instantaneous flow for the exact point in time at which the water quality sample is collected and the mean daily flow, is generally negligible.

Because the water quality values and flows are dependent, one would like to see if a trend is present in the logarithmic water quality time series after the flow effects are removed. To accomplish this, one can examine the residuals of the RLWRS in Figure 3.2 . To calculate the residual for each plotted point in Figure 3.2, one subtracts the value of the RLWRS at that point. For convenience, a RLWRS using RS50 is used when calculating the residuals. This series is called the flow-adjusted water quality time series.

Figure 3.3 presents a trace of the flow-adjusted NO_x data for the Saugeen River. Notice that even after flow effects are removed, the RLWRS still shows an obvious upward trend over

Table 3.1. Trend analysis methodology for use with water quality time series measured in rivers.

TREND ANALYSIS METHODOLOGY

GRAPHICAL TREND STUDIES

Examine traces along with smoothed curves (i.e., RLWRS's) for the following data sets:

Given Data:

1. Unadjusted water quality time series.
2. Flow-adjusted water quality time series.
3. Detrended-flow-adjusted water quality time series.

Mean Monthly Data:

4. Mean monthly unadjusted water quality time series.
5. Mean monthly flow-adjusted water quality time series.
6. Mean monthly detrended-flow-adjusted water quality time series.

TREND TESTS

For the there means monthly data sets (i.e., 4, 5 and 6) the following trend tests are carried out:

a. Mann-Kendall (Section 2.3.2).

b. Spearman's rho (Section 2.3.4).

c. Seasonal Mann-Kendall (Section 2.3.5).

d. Spearman partial rank correlation when partialling out seasonality (Section 2.3.7).

To test for seasonality, the Kruskal-Wallis test (Section 2.3.6) and box and whisker graphs (Section 2.2.3) can be used. The tests under c and d are designed for use with seasonal data.

time.

3. Detrended-flow-adjusted water quality time series: If a trend were present in the flow or covariate series, one would want to remove this trend and then subsequently adjust the water quality time series for detrended flow. In this step, a flexible procedure obtaining a detrended-flow-adjusted water quality series is described.

Table 3.2. Algorithm for the Spearman partial rank correlation trend test when partialling out seasonality.

ALGORITHM

1) X_t is one of the three monthly series given under 4, 5 and 6 in Table 3.1.
2) Test for the presence of seasonality in X_t using
   a. Box and whisker graphs (Section 2.2.3).
   b. Kruskall-Wallis test (Section 2.3.6).
3) If seasonality is not found, use the ordinary Mann-Kendall trend test (Section 2.3.2).
4) When seasonality is present, carry out the Spearman partial rank correlation test of Section 2.3.7 where:
   a. X_t is the series from 1).
   b. $Y_t=t$ where t is the time of the observation.
   c. Z_t is obtained from the ranking of the seasonal effects in the Kruskall-Wallis test (Section 2.3.6).

Suppose, for now, that the NO_x series really does not have a trend. Flows may cause a trend to appear in the series due to one or both of the following two reasons. First, there may be a real trend in the flows which also causes a trend in the NO_x series. Second, the sampling bias of the flows may cause a trend. Recall that in Figure 3.2, each flow is plotted for exactly the same time as the corresponding NO_x observation so that many of the flow observations are not used when producing the flow-adjusted NO_x series. When the complete series of logarithmic Saugeen flows are plotted against time, no trend is present. However, when the logarithmic flows are plotted against time for exactly the same times at which the NO_x values are measured, Figure 3.4 shows that the sampling bias has created an obvious trend. To remove the trend from the logarithmic flow series in Figure 3.4, one can subtract the RLWRS value from the logarithmic NO_x series at each time point for which an NO_x observation is available. This residual series is determined for a RLWRS using RS50 to obtain the detrended logarithmic flow series.

Figure 3.5 displays a scatter plot of the logarithmic NO_x series against the detrended logarithmic flows. Notice that there is still a dependence between the two series even after the trend due to sampling bias is removed from the logarithmic flows. To obtain the detrended-flow-adjusted NO_x series, one uses the residuals of the RLWRS for the case when RS50 is used to determine the smooth.

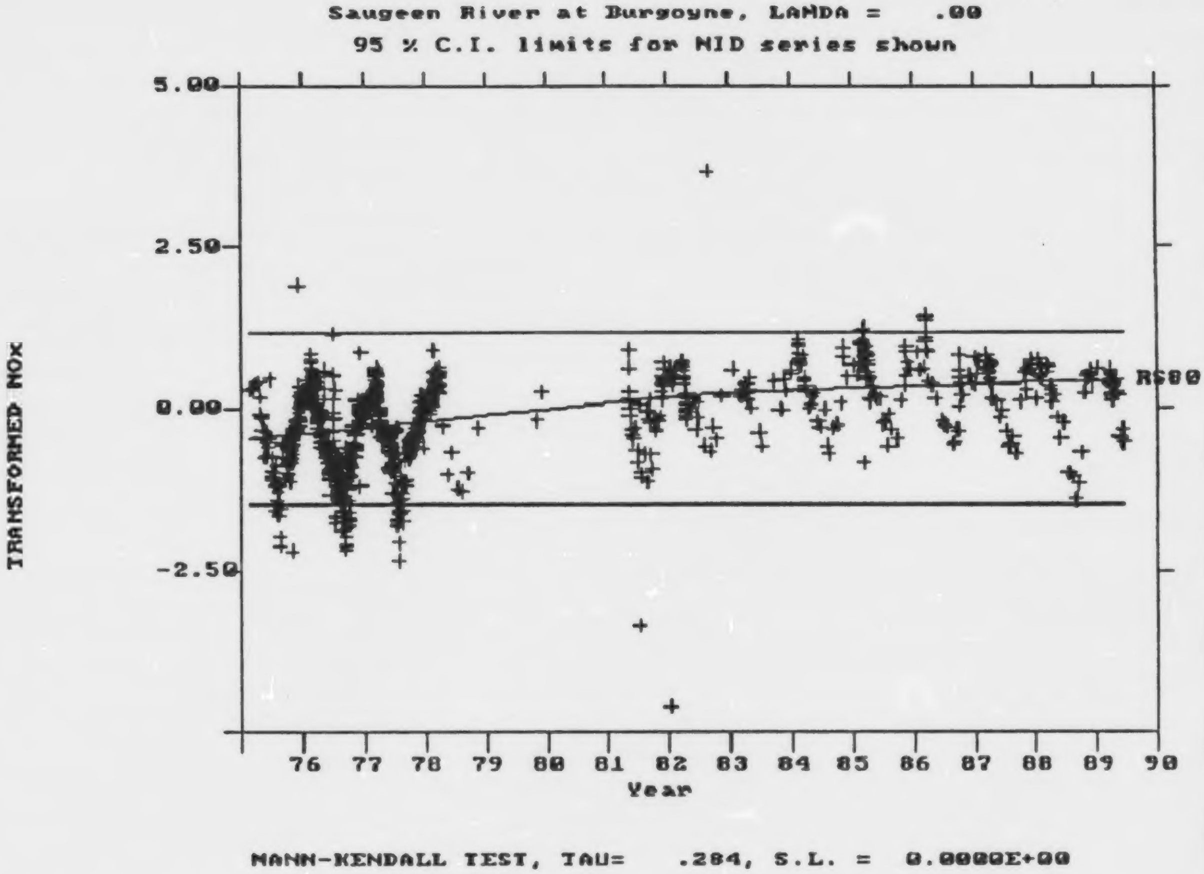

Figure 3.1. Graph of the logarithmic total nitrates denoted by NO_x (mg/l) against time for the Saugeen River.

For the Saugeen River data, the complete flow record possesses no trend. Because of this, one can state that the trend in the partial flow record plotted in Figure 3.4 is due to sampling bias. If the complete record of flows contained a trend, then a trend in the partial flow record (i.e. those flows occurring on the same days at which the water quality samples were collected) would be due to an actual trend in the flows and perhaps also sampling bias.

Figure 3.6 shows a graph of the detrended-flow-adjusted data against time. Both the RLWRS and the Mann-Kendall trend test result in this figure show that there is a trend.

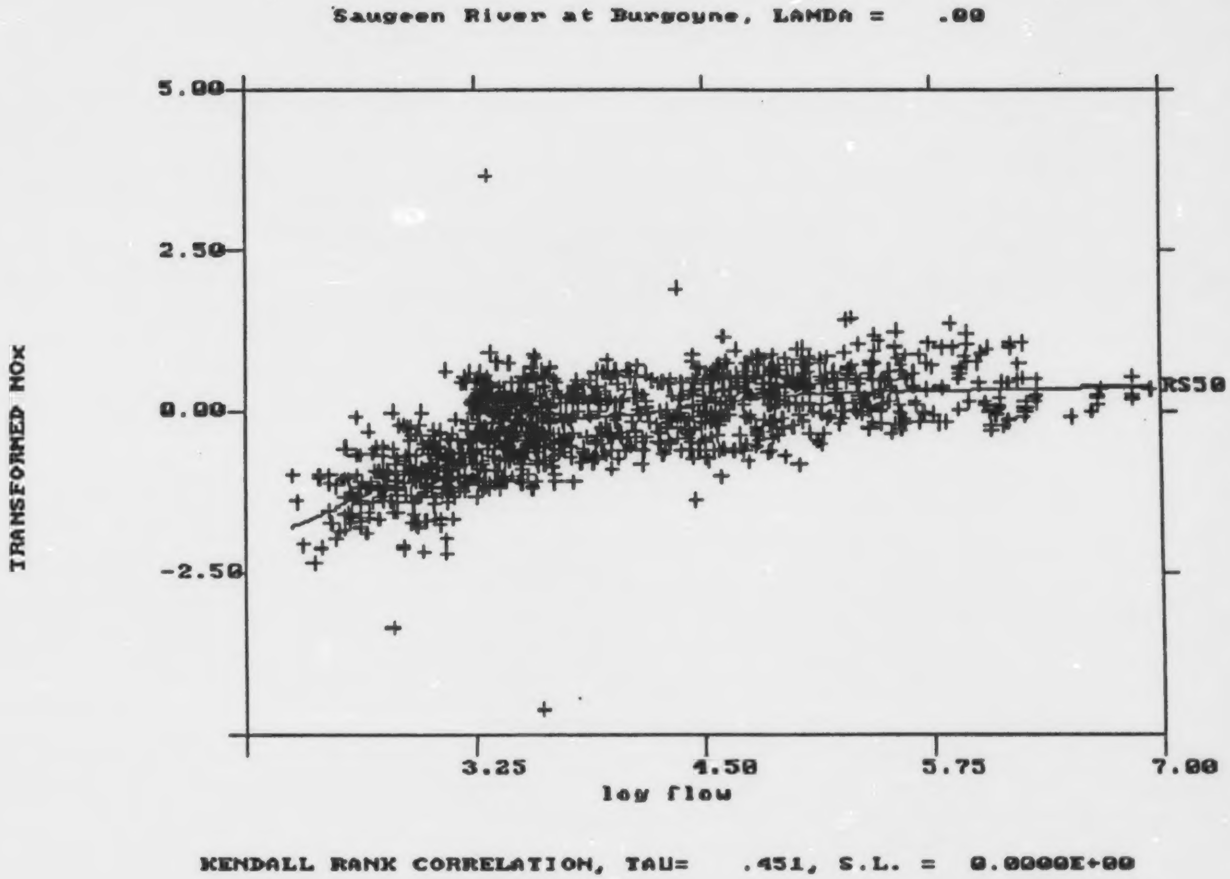

Figure 3.2. Scatter plot of logarithmic total nitrates (mg/l) against logarithmic flows (m^3/s) for the Saugeen River.

Mean Monthly Data

4. Mean monthly unadjusted water quality series: To ascertain the behaviour of the NO$_x$ series at the monthly level, one can examine graphs of the average monthly series. One should keep in mind that the term "average" refers to calculating a mean which may be determined from only a few observations in a given month, each of which is collected in a 10 to 15 second time interval (see discussion on missing values in Section 2.1). Figure 3.7 shows a graph of the logarithms of the mean monthly NO$_x$ series for the Saugeen River. The RLWRS shows that there is an increasing trend over time. Additionally, there are some months for which no observations are available.

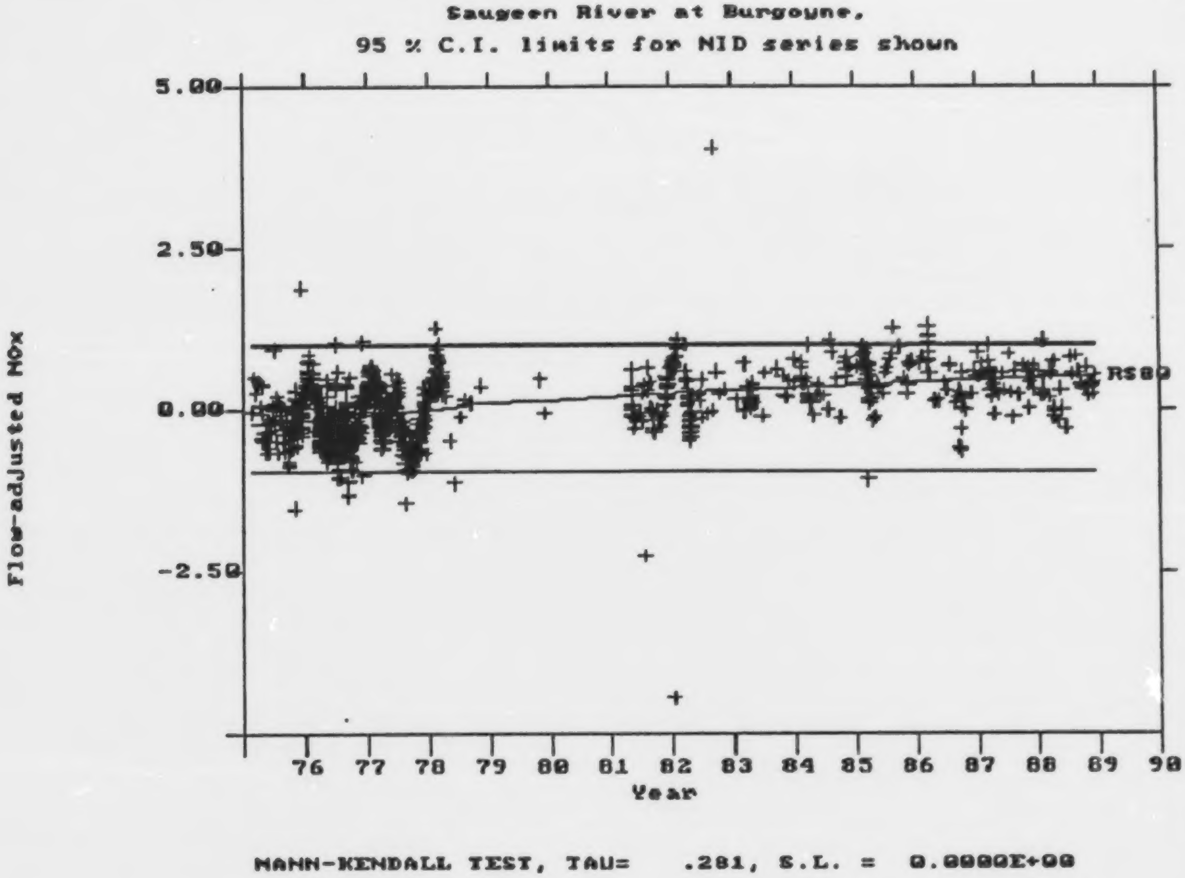

Figure 3.3. Graph of the flow-adjusted NO_x series against time for the Saugeen River.

5. Mean monthly flow adjusted water quality time series: Except for the fact that monthly values are used, the logarithmic mean monthly flow-adjusted NO_x series is calculated in exactly the same way as the logarithmic flow-adjusted water quality time series for the given data. Hence, one determines the residuals of the RLWRS using RS50 fitted to a scatter plot of logarithmic mean monthly NO_x series against the logarithmic mean monthly flows. Figure 3.8 displays the graph of the mean monthly flow adjusted water quality series against time, for which there is a striking linear upward trend.

6. Mean monthly detrended-flow-adjusted water quality time series: To eliminate the effects of trends and/or sampling bias in the monthly flows upon the average monthly NO_x series one can calculate the average monthly detrended-flow-adjusted data. The same procedure followed for determining the flows under item 3 for the given data is also employed here. First,

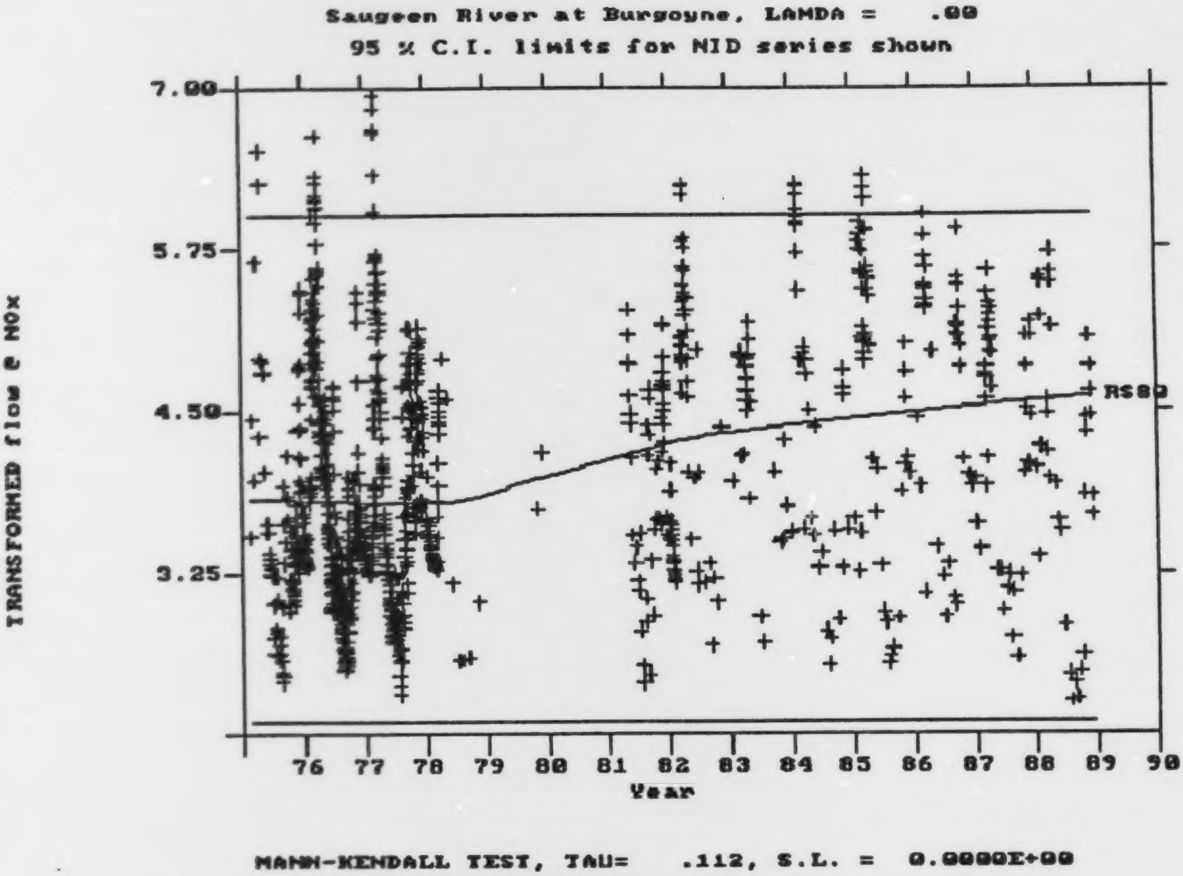

Figure 3.4. Logarithmic Saugeen flows against time plotted at exactly the same times at which NO_x observations are available.

one fits a RLWRS using RS50 to a graph of the logarithmic mean monthly flows against time where the flow observations are only used for months for which NO_x values are available. The residuals of the smooth form the logarithmic mean monthly detrended flow series. Second, a RLWRS smooth using RS50 is fitted to a scatter plot of the logarithmic mean monthly NO_x series against the logarithmic mean monthly detrended flow series. The residuals of this smooth constitute the logarithmic average monthly detrended-flow-adjusted NO_x series.

Figure 3.9 displays a plot of the logarithmic average monthly detrended flow adjust time series against time. The RLWRS clearly reveals the increasing trend present in this data.

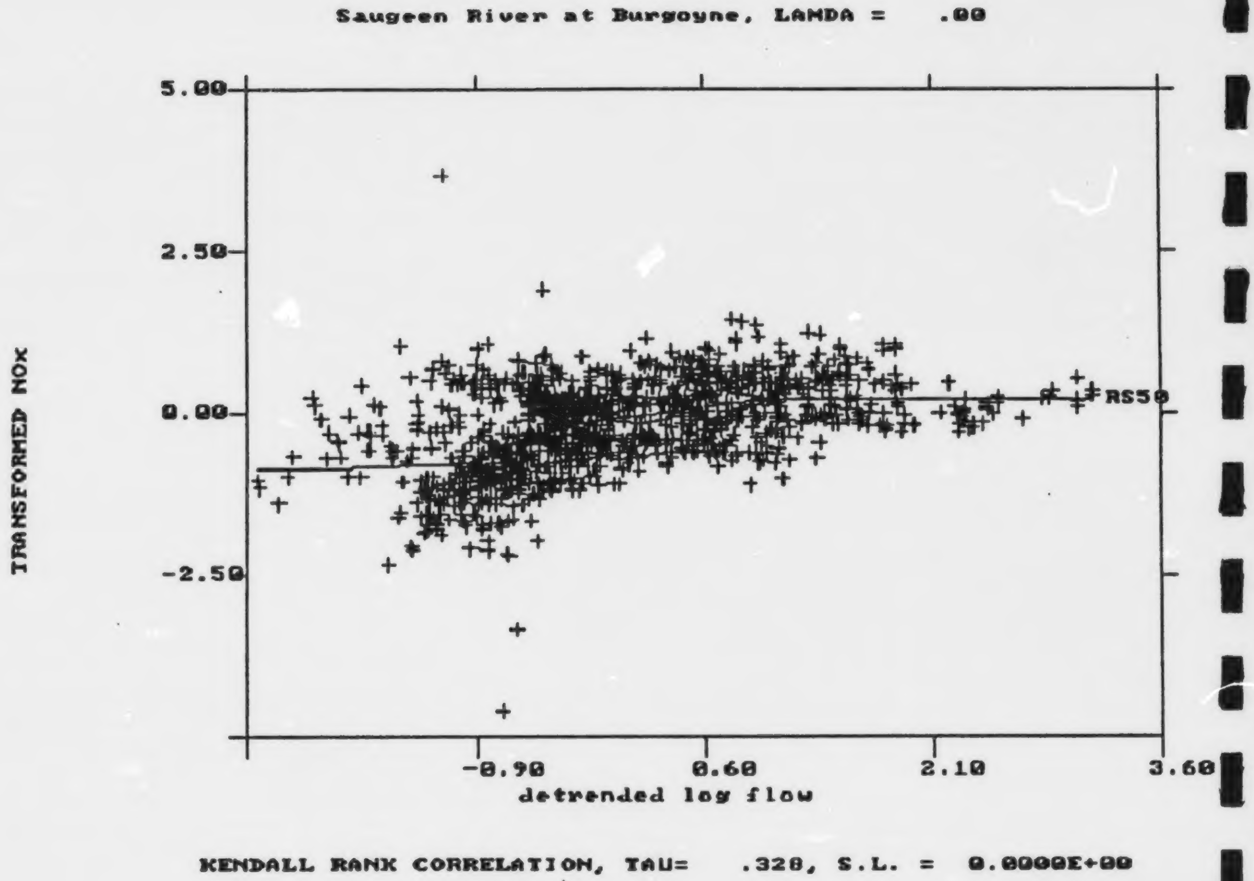

Figure 3.5. Scatter plot of the logarithmic NO_x data against detrended logarithmic flows for the Saugeen River.

3.2.2 Trend Tests

The four trend tests listed in Table 3.1 are applied separately to each of the three types of mean monthly series. For all three series, the four trend tests give exactly the same results. Because of this, representative results are presented for only one of the three monthly series for explanation purposes in this section. The reader can refer to the Appendix to see the detailed findings for the other two series.

Consider the fifth series which is the logarithmic mean monthly flow-adjusted NO_x series for the Saugeen River. Table 3.3 presents the results for the four trend tests for this series while Table 3.4 gives the average rank value and rank found for each of the twelve seasons used in the Kruskal-Wallis seasonality test. Finally, Figure 3.10 and also Figure 2.3 displays the box and whisker graph for each of the 12 months for the series being considered. The reader can refer to

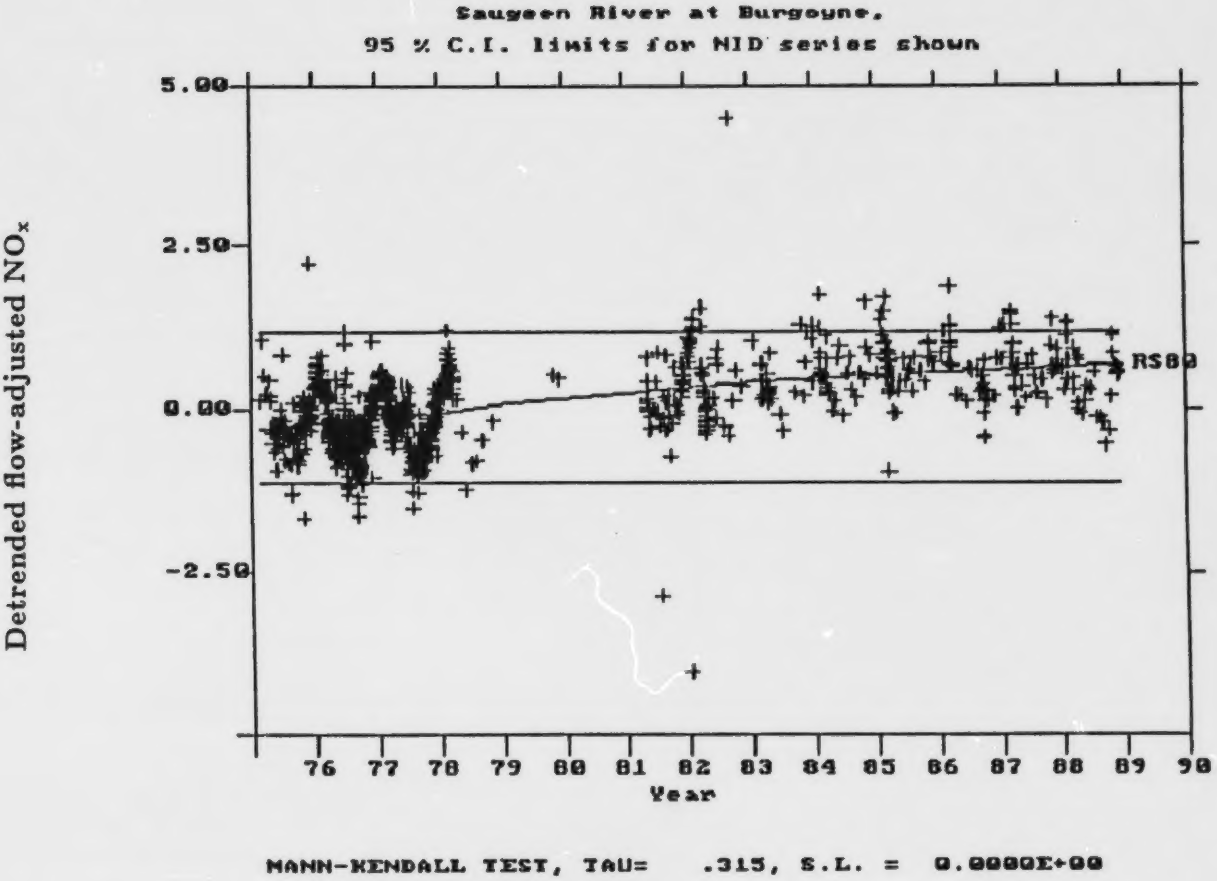

Figure 3.6. Graph of detrended-flow-adjusted logarithmic NO_x observations against time for the Saugeen River.

Section 2.3 for descriptions of the statistical trend tests and to Section 2.2.3 for an explanation of box and whisker graphs.

Each of the four trend tests in Table 3.3 demonstrate that there is a significant trend. In particular, notice that the significance levels are very close to zero for the Mann-Kendall (Section 2.3.2), Spearman's rho (Section 2.3.4), seasonal Mann-Kendall (Section 2.3.5) and the Spearman partial rank correlation (Section 2.3.7) trend tests. This same application results are also presented with the trend test descriptions in Section 2.3.

The test statistic in Table 3.4 for the Kruskall-Wallis test has a value of 47.519 and a significance level close to zero. Hence, there is seasonality present in the series. One can also see the cyclic pattern caused by seasonality in the box and whisker graphs for this NO_x series in Figure 3.10. Notice, in particular how the median levels change from month to month.

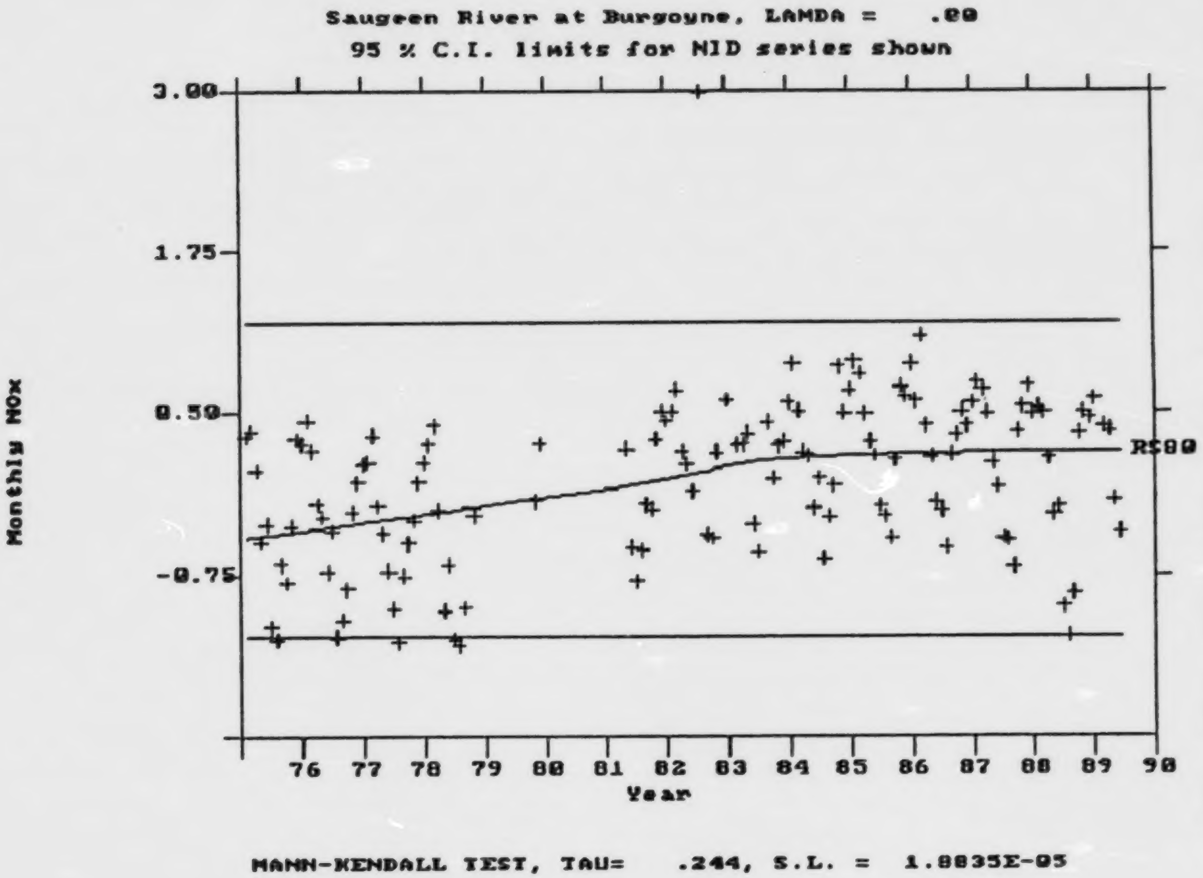

Figure 3.7. Graph of the logarithmic average monthly series against time for the Saugeen River at Burgoyne.

Because of the importance of the Spearman partial rank correlation test for detecting trends in seasonal data, consider the results of this test in more detail. The algorithm for this test is given in Table 3.2. In this case, the X_t is the fifth series which is the logarithmic mean monthly flow adjusted NO$_x$ series for the Saugeen River. Under Step 2 of the algorithm in Table 3.2, the Kruskall-Wallis test result in Table 3.4 as well as the box and whisker graphs of Figure 3.10 demonstrate that the data are seasonal. In Table 3.4, the seasons are ranked from smallest to largest according to the average rank values for the months. The monthly medians in Figure 3.10 can also be compared to obtain the same rankings. Following Step 4 of the algorithm in Table 3.2, one lets the Y_t series in the Spearman test be time t while Z_t consists of the seasonal ranks where each month across the years is always given the same rank. By substituting into Equations 2.39, one can obtain the Spearman test statistic which has a value of 0.572. Because

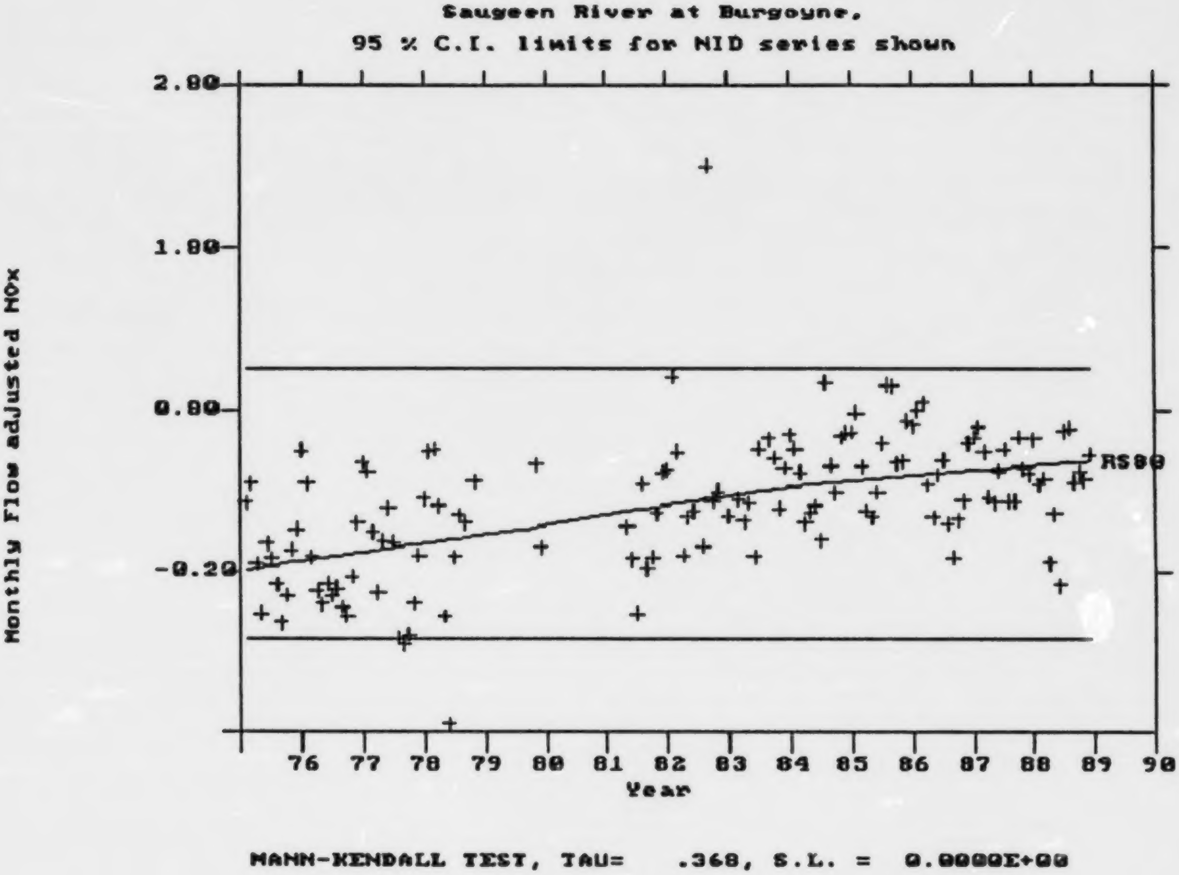

Figure 3.8. Graph of the logarithmic mean monthly flow-adjusted NO_x series against time for the Saugeen River at Burgoyne.

the SL is almost zero, there is a significant trend over time in the data when the effects of seasonality are partialled out. Since the test statistic is positive, the trend is increasing over time.

3.3 Summary

A flexible and comprehensive trend analysis methodology is now available for carrying out a systematic study for detecting and modelling trends in water quality series measured in rivers. As summarized in Table 3.1, the two mean components to the methodology are the Graphical Trend Studies and the Trend Tests. Of particular import and usefulness for analyzing trend in seasonal water quality data is the Spearman partial rank correlation test of Section 2.3.7. When using this test for detecting a trend in a seasonal series for which seasonality is partialled out, the Spearman algorithm of Table 3.2 can be utilized. Finally, the overall methodology contains

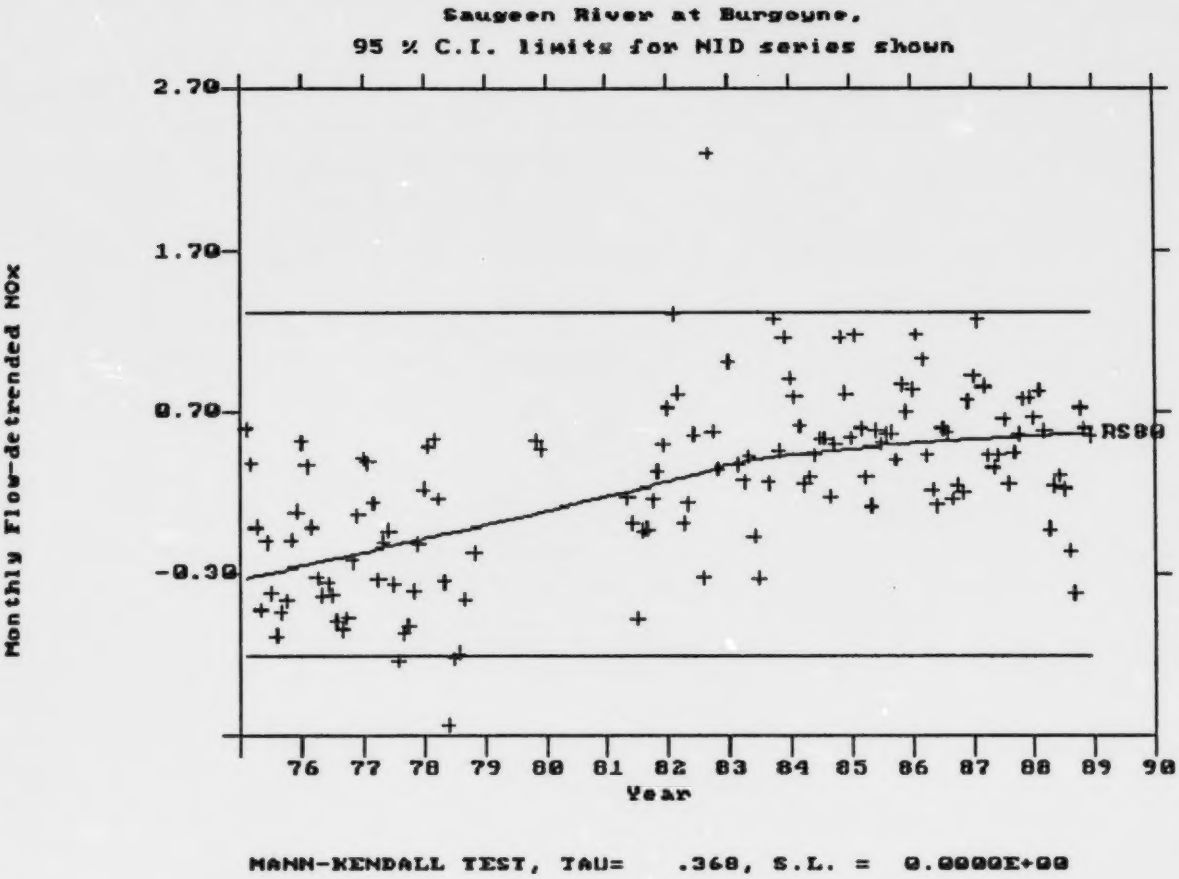

Figure 3.9. Graph of the logarithmic average monthly detrended-flow-adjusted data for the Saugeen River at Burgoyne.

Table 3.3. Trend test results for the logarithmic mean monthly flow-adjusted NO_x series for the Saugeen River at Burgoyne.

Trend Tests	Test Statistics	Significance Levels
Mann-Kendall	0.368	0.000
Spearman's Rho	0.542	0.000
Seasonal	314	0.000
Spearman Partial Rank Correlation	0.572	0.000

Table 3.4. Average ranks and ranks from the Kruskal-Wallis analyses for the 12 months of the logarithmic mean monthly flow-adjusted NO_x series for the Saugeen River at Burgoyne.

Months	Sample Sizes	Average Rank Values	Ranks
1	10	89.5000	6
2	10	107.700	7
3	11	107.364	7
4	11	92.2727	6
5	12	42.0000	2
6	12	37.1667	1
7	11	46.1818	2
8	11	60.8182	4
9	12	68.3333	5
10	11	54.3636	3
11	13	57.9231	3
12	11	64.9091	4

Test statistic = 47.519 Significance level = 0.000

procedures for accounting for the effects of flow upon a given water quality variable.

At various locations in Section 3, it is noted that one could, if required, use additional graphs and trend tests within the overall trend analysis methodology of Table 3.1. For instance, one may wish to employ the adjusted variable Kendall trend test proposed by Alley (1988). However, the authors found that the specific exploratory and confirmatory techniques presented in Section 2, readily handled all the situations that arose when examining the water quality series from the Saugeen and Grand Rivers in Southern Ontario.

Another approach to the trend analysis would be to add a deseasonalization step either before or after Step 2 in Table 3.1. However, this procedure is not followed here for a number of reasons. First, adjusting the water quality series for flow or some other covariate series may also remove some seasonality. Secondly, an efficient procedure for removing seasonality from a wide variety of messy water quality time series may be very difficult to design. Finally, when seasonality is present in the data sets numbered 4 to 6, a seasonal trend test can be used for checking for the presence of trends in seasonal data (trend tests under c and d in Table 3.1).

As demonstrated by the applications to the total nitrates data for the Saugeen River, the methodology of Section 3.2 works well in practice. In Table 3.5, a summary of the findings for the NO_x data is presented. For both the graphical trend studies and the trend tests, trends are always detected in the versions of the NO_x series that are examined. Table 3.6 lists the order in which the graphical and trend tests results are presented in the Appendix for the NO_x series for the Saugeen River. For explanation purposes, these results are presented in a slightly different order in Section 3.2. Within Section 4, the main findings of all the trend studies are summarized while detailed results for all the water quality series for both the Saugeen and Grand Rivers are

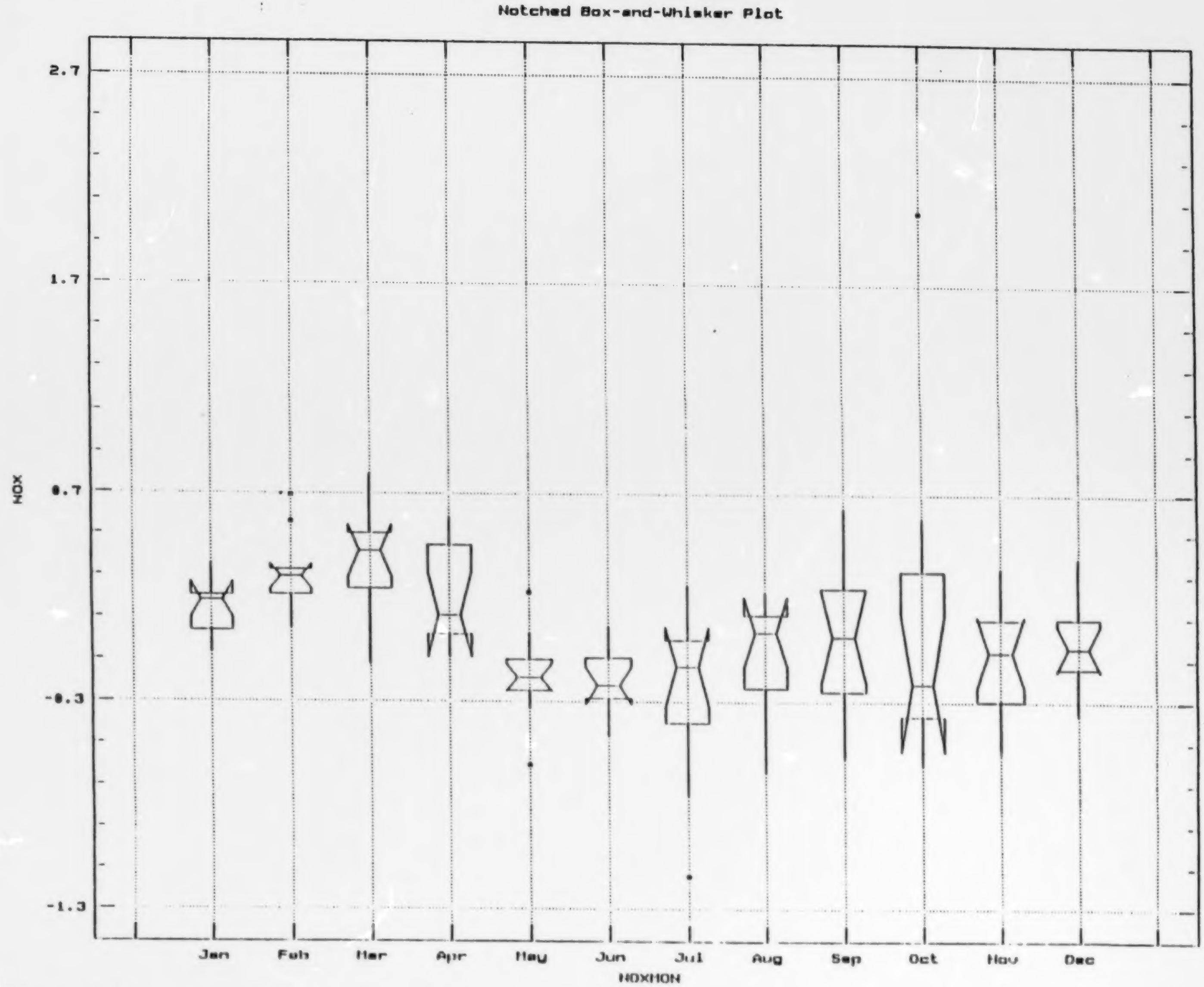

Figure 3.10. Box and whisker graphs for the logarithmic mean monthly flow-adjusted NO_x series for the Saugeen River at Burgoyne.

listed in the Appendix.

Table 3.5. Summary of the trend analysis results for the total nitrates data measured in the Saugeen River at Burgoyne.

Data Transformation: Logarithmic

Seasonality: Very strong

Flow-Concentration Relationship: Positive relationship at low flow with relatively constant relationship at higher flow.

Outliers: A few (see Figure 3.1). Keep in mind that all techniques used in Table 3.1 are robust to outliers.

Trend: All tests indicate a significant trend. Examination of the trace plots suggest that it is largely due to a difference in levels in the data from 1975-1978 and 1982-1989.

Other: Very little data over the period 1979-1981.

4. APPLICATIONS

4.1 Introduction

In this section, the general trend analysis methodology of Section 3 is applied to water quality data measured at two rivers located in Southern Ontario. Time series for the eight water quality variables (mg/l) listed in Table 4.1 as well as riverflow series (m^3/s), are available for the Saugeen River at Burgoyne and also the Grand River at Dunnville. Within Section 4.2, the main results of the trend analysis studies for the water quality time series of Table 4.1 are summarized while the reader can refer to the Appendix in order to find detailed graphical and numerical results for each of the series. For a good discussion on how to apply the trend analysis methodology, one can read Section 3.2 where the total nitrate series for the Saugeen River is employed for illustrative purposes.

For the case of the NH_x and TKN series for the Saugeen River, data are available in the first few years of the series while few measurements are taken after that time. Therefore, as shown in the appendix for these two series, only a few graphs are presented and the complete trend analysis methodology is not applied to these data sets. However, for all of the remaining water quality series for the Saugeen River and also all eight water quality time series for the Grand River, the trend analysis procedure is applied in full. Table 3.6 lists the types of output obtained for the NO_x series from the Saugeen River. These same kinds of information are also found for all of the other water quality time series for which complete trend analyses are executed (see the Appendix).

Table 3.6. List of graphical studies and trend tests carried out for the total nitrates data measured on the Saugeen River at Burgoyne.

Table of Contents: Saugeen.NO_x

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs NO_x

(9) Scatter and smooth of detrended-flow vs NO_x

(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box and whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Similar to Table 3.5 for the NO_x series for the Saugeen River, a summary and conclusions table is provided for each of the series in the Appendix, including the two riverflow series. Except as indicated for a few cases in which no data tansformation is taken, the data transformation employed is natural logarithms. In particular, for the alkalinity and conductivity series, no data transformation is invoked.

4.2 Main Findings

As explained in Section 3.2, three kinds of mean monthly data are subjected to trend studies within the overall procedure. The results of the trend tests for these three trend series are presented in Tables 4.2 to 4.4 for the Saugeen River while the findings for the Grand River are given in Tables 4.5 to 4.7.

Table 4.1. Water quality variables measured in the Saugeen River at Burgoyne and the Grand River at Dunnville, Ontario.

Water Quality Variable	Symbol
Ammonia Nitrogen	NH_x
Total Kjeldahl Nitrogen	TKN
Total Nitrates	NO_x
Filtered Reactive Phosphorus	FRP
Total Phosphorus	TP
Suspended Solids	SS
Alkalinity	ALK
Conductivity	CND

4.2.1 Results for the Saugeen River

Consider first Table 4.2 which lists trend test results for the mean monthly unadjusted water quality time series measured in the Saugeen River. The first column gives the water quality series studied. Notice also at the bottom of this column that the trend test findings for the mean monthly flow are also provided. The second column presents the results of the Kruskall-Wallis test for seasonality (see Section 2.3.6) for each of the series in the first column. The three stars indicate that for each of the series, the test confirms the presence of strong seasonality at the 0.1% SL or 0.001 SL.

The next two columns give the SL's for the Mann-Kendall (Section 2.3.2) and seasonal Mann-Kendall (Section 2.3.5) trend tests. Finally, the last two columns present the SL for the Spearman partial rank correlation trend test (Section 2.3.7) for each series as well as the value of the Spearman rank correlation coefficient (Equation 2.39) when seasonality is partialled out. Table 3.2 describes the steps followed for applying the Spearman partial rank correlation trend test when partialling out seasonality. A positive value for the coefficient in Equation 2.39 indicates an upward trend while a negative value means that the trend is downwards.

In the bottom row of Table 4.2, all the trend tests indicate that the Saugeen flows do not possess any trends. As can be seen, for the case of the mean monthly unadjusted NO_x series, all three trend tests point out that there is a strong upward trend in this series.

For the Saugeen River, Tables 4.3 and 4.4 present the trend test results for the mean monthly flow-adjusted water quality series and the mean monthly detrended-flow-adjusted water quality series, respectively. Notice that across all three tables, the various NO_x series for the Saugeen River always possess strong upward trends.

There are many other interesting results for water quality times series in the Saugeen River. For the case of TP, some slight trends are detected mainly at the 5% SL for the unadjusted (Table 4.2) and flow-adjusted (Table 4.3) series. However, for the detrended-flow-adjusted TP series (Table 4.4), notice that none of the tests indicate that a trend is present.

Table 4.2. Trend test results for the mean monthly unadjusted water quality time series measured in the Saugeen River at Burgoyne.

		TREND TESTS RESULTS			
Water Quality Variables	Kruskall-Wallis Seasonality Test	Mann-Kendall Trend Test	Seasonal Mann-Kendall Trend Test	Spearman Partial Rank Correlation Trend Test	Spearman Partial Rank Correlation Coefficient
NO_x	***	***	***	***	0.48
FRP	***	-	-	-	-0.12
TP	***	*	**	*	-0.17
SS	***	-	-	-	0.07
ALK	***	-	-	-	0.11
CND	***	-	-	-	0.06
Flow	***	-	-	-	-0.08

Legend:

*** significant at 0.01% level
** significant at 1% level
* significant at 5% level
- not significant (SL is greater than 0.05)

For the ALK series for the Saugeen River, strong trends are only detected for the mean monthly flow-adjusted series (Table 4.3). This ALK series has some rather interesting relationships with flow. The scatter plot in Figure 4.1 for the alkalinity measurements versus the natural logarithms of flow shows the "inverted u" dependence between ALK and flow. When the scatter plot of ALK against detrended logarithmic flow is examined, one can see from Figure 4.2 that there is still a nonlinear dependence. Finally, Figure 4.3 demonstrates that when logarithmic flow is plotted against time for exactly the same times at which the original ALK observations are taken, there is an obvious upward trend in the flows. This trend is due to sampling bias because a graph of the entire Saugeen flow record does not possess any trend. This sampling bias may cause the trend detected in the flow adjusted ALK series in Table 4.3. However, the detrended-flow-adjusted ALK series in Table 4.4 does not have this strong trend caused by sampling bias. Only at the 5% SL does one of the three trend tests indicate a slight trend.

For the CND series for the Saugeen River, an upward trend is detected at the 5% SL for the flow-adjusted series in Table 4.3. However, as is also more or less the case for ALK, no trend is found for the unadjusted (Table 4.2) or detrended-flow-adjusted (Table 4.4) CND series.

As a final observation, notice that when a water quality series is adjusted for flow (Table 4.3) or detrended flow (Table 4.4), the affects of seasonality may become less pronounced. For instance, in Table 4.4 the TP and SS detrended-flow-adjusted water quality time series do not possess seasonality even though the corresponding series in Table 4.2 are strongly seasonal. The flow-adjusted version of these two series in Table 4.3 have some seasonality.

Table 4.3. Trend test results for the mean monthly flow-adjusted water quality time series measured in the Saugeen River at Burgoyne.

		TREND TESTS RESULTS			
Water Quality Variables	Kruskall-Wallis Seasonality Test	Mann-Kendall Trend Test	Seasonal Mann-Kendall Trend Test	Spearman Partial Rank Correlation Trend Test	Spearman Partial Rank Correlation Coefficient
NO_x	***	***	***	***	0.57
FRP	***	-	-	-	-0.10
TP	5.6%	*	*	*	-0.17
SS	*	* (4.8%)	30.8%	7.3%	0.16
ALK	*	***	***	***	0.34
CND	***	*	*	*	0.22

Legend:

*** significant at 0.01% level
** significant at 1% level
* significant at 5% level
- not significant (SL is greater than 0.05)

4.2.2 Results for the Grand River

Tables 4.5 to 4.7 display the results of the trend assessment study for the three types of monthly water quality series for the Grand River. In the last row of Table 4.5, the trend tests results for flow are presented. As would be expected, the monthly flows are strongly seasonal. When one examines the graph of the logarithmic monthly flows against time shown in Figure 4.4, there appears to be a slight upward trend. However, a shown by the results of the trend tests in Table 4.5, this trend is not significantly different from zero at the 5% SL. Nonetheless, when the drought year of 1988 is omitted from the data set, the trend becomes significant at less than 1% when using the Spearman partial rank correlation trend test. Because one examines mean monthly detrended-flow-adjusted water quality time series in Table 4.7, any trend in the riverflows is first removed before eliminating the effects of flow on a given water quality time series.

As is also the case for the unadjusted Saugeen series, the results of the Kruskall-Wallis test show that all of the series in Table 4.5 are strongly seasonal. However, unlike the Saugeen series, the flow-adjusted and detrended-flow-adjusted versions of the water quality series in Table 4.6 and 4.7, respectively, remain strongly seasonal.

All three versions of the TP series for the Grand River possess strong decreasing trends. The three monthly TP series corresponding to Tables 4.5 to 4.7 are plotted in Figures 4.5 to 4.7, respectively. In all three figures the RLWRS clearly depicts the decreasing trend.

The unadjusted TKN series for the Grand River does not possess any trend (Table 4.5). However, notice that the flow-adjusted version of this series possesses a slight downward trend (Table 4.6) while the detrended-flow-adjusted TKN series (Table 4.7) has a moderately strong

Table 4.4. Trend test results for the mean monthly detrended-flow-adjusted water quality time series measured in the Saugeen River at Burgoyne.

		TREND TESTS RESULTS			
Water Quality Variables	Kruskall-Wallis Seasonality Test	Mann-Kendall Trend Test	Seasonal Mann-Kendall Trend Test	Spearman Partial Rank Correlation Trend Test	Spearman Partial Rank Correlation Coefficient
NO_x	***	***	***	***	0.61
FRP	**	-	-	-	0.03
TP	-	-	-	-	-0.00
SS	-	*	-	*	0.21
ALK	**	-	-	*	0.19
CND	*	-	-	-	-0.11

Legend:

*** significant at 0.01% level
** significant at 1% level
* significant at 5% level
- not significant (SL is greater than 0.05)

downward trend.

Alkalinity possesses upward trend in the unadjusted (Table 4.5) and detrended-flow-adjusted (Table 4.7) types of series. However, there is no significant trend present in the flow-adjusted ALK series in Table 4.6.

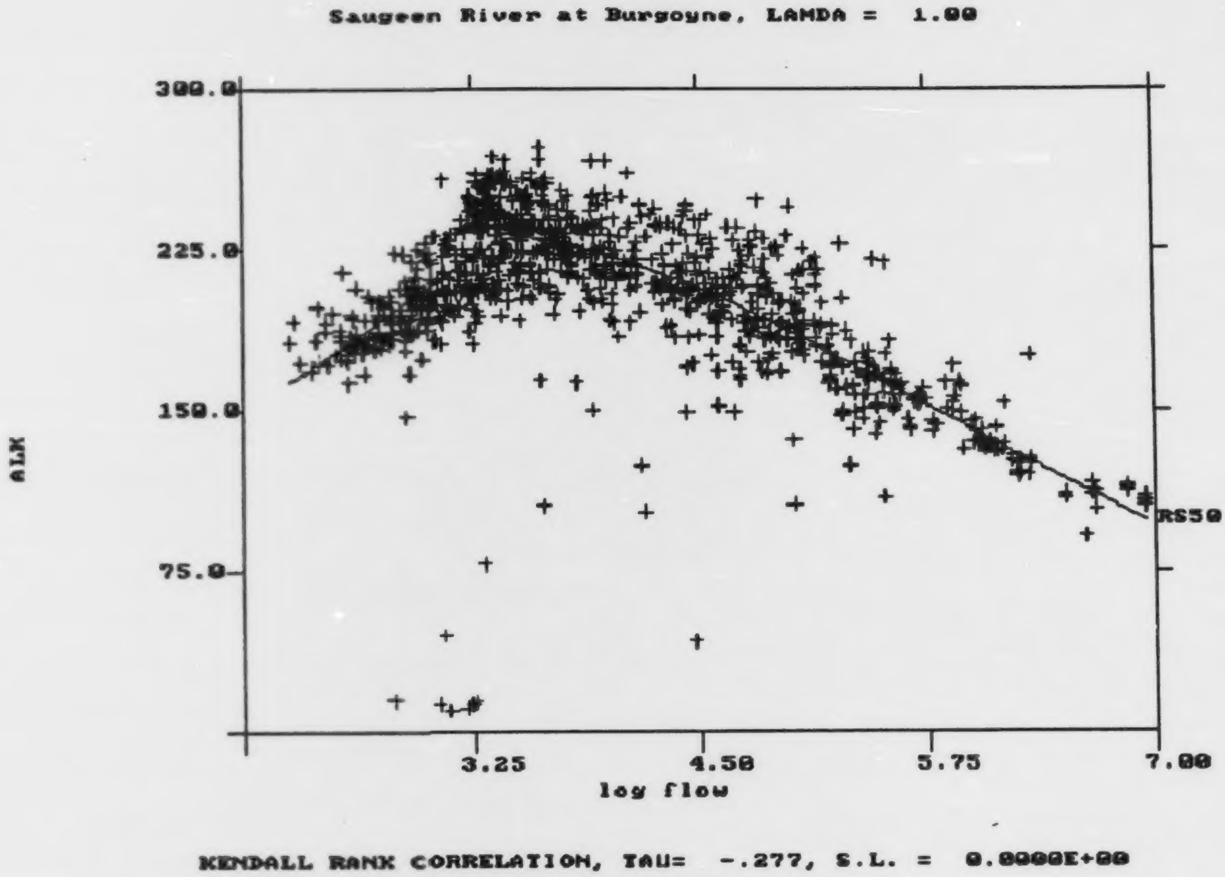

Figure 4.1. Scatter plot of alkalinity (mg/l) against logarithmic flows (m^3/s) for the Saugeen River at Burgoyne.

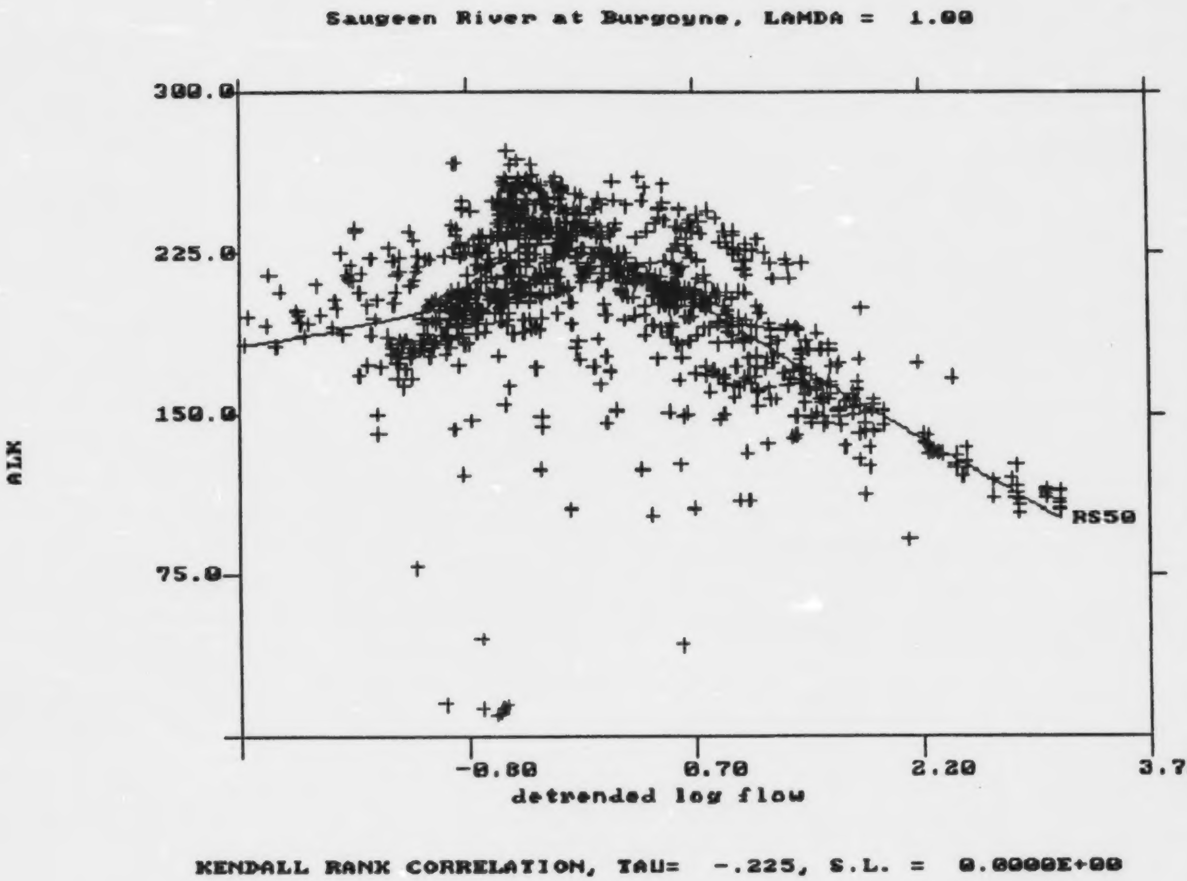

Figure 4.2. Scatter plot of alkalinity versus detrended logarithmic flows for the Saugeen River at Burgoyne.

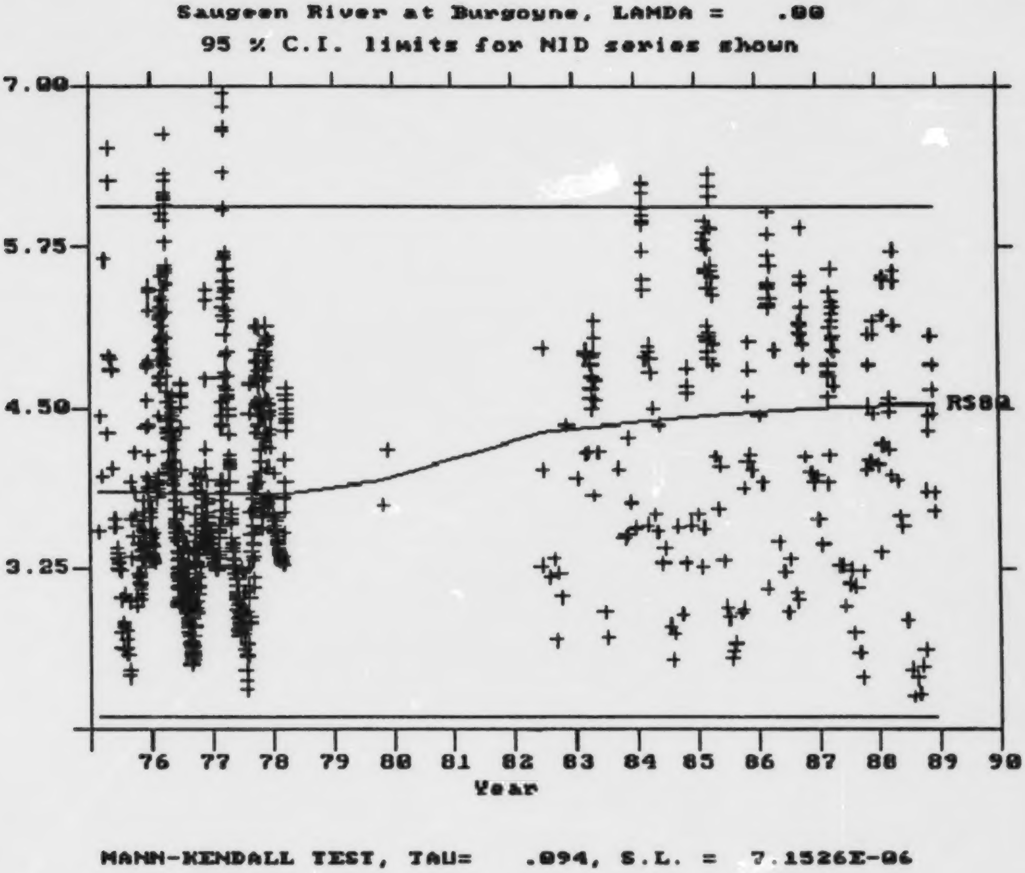

Figure 4.3. Logarithmic Saugeen flows against time plotted at exactly the same time at which the ALK observations are available.

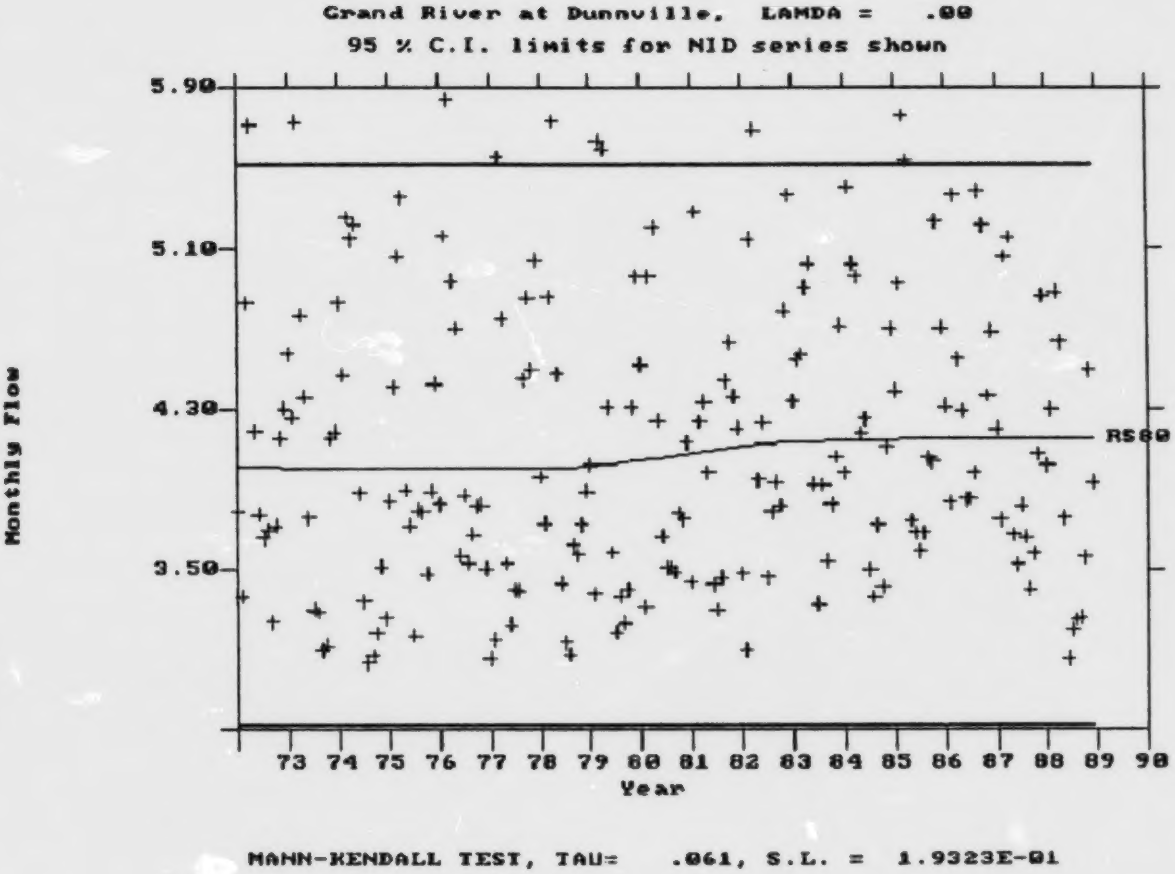

Figure 4.4. Graph of logarithmic average monthly flows of the Grand River at Dunnville.

Table 4.5. Trend test results for the mean monthly unadjusted water quality time series measured in the Grand River at Dunnville.

		TREND TESTS RESULTS			
Water Quality Variables	Kruskall-Wallis Seasonality Test	Mann-Kendall Trend Test	Seasonal Mann-Kendall Trend Test	Spearman Partial Rank Correlation Trend Test	Spearman Partial Rank Correlation Coefficient
NH_x	***	-	-	-	-0.02
TKN	***	-	-	-	-0.08
NO_x	***	***	***	***	0.30
FRP	***	*	-	*	-0.15
TP	***	***	***	***	-0.30
SS	***	-	-	-	0.03
ALK	***	*	**	*	0.15
CND	***	*	***	*	0.16
Flow	***	-	-	-	0.12

Legend:

*** significant at 0.01% level
** significant at 1% level
* significant at 5% level
- not significant (SL is greater than 0.05)

Table 4.6. Trend test results for the mean monthly flow-adjusted water quality time series measured in the Grand River at Dunnville.

		TREND TESTS RESULTS			
Water Quality Variables	Kruskall-Wallis Seasonality Test	Mann-Kendall Trend Test	Seasonal Mann-Kendall Trend Test	Spearman Partial Rank Correlation Trend Test	Spearman Partial Rank Correlation Coefficient
NH_x	***	-	-	-	-0.11
TKN	***	*	*	*	-0.17
NO_x	***	-	*	*	0.15
FRP	***	**	**	**	-0.22
TP	***	***	***	***	-0.42
SS	***	-	-	-	-0.05
ALK	***	-	-	-	0.07
CND	***	***	***	***	0.30

Legend:

*** significant at 0.01% level
** significant at 1% level
* significant at 5% level
- not significant (SL is greater than 0.05)

Table 4.7. Trend test results for the mean monthly detrended-flow-adjusted water quality time series measured in the Grand River at Dunnville.

		TREND TESTS RESULTS			
Water Quality Variables	Kruskall-Wallis Seasonality Test	Mann-Kendall Trend Test	Seasonal Mann-Kendall Trend Test	Spearman Partial Rank Correlation Trend Test	Spearman Partial Rank Correlation Coefficient
NH_x	***	-	-	-	-0.09
TKN	***	**	**	**	-0.22
NO_x	***	***	***	***	0.35
FRP	***	-	-	-	-0.09
TP	***	***	***	***	-0.37
SS	***	-	-	-	-0.02
ALK	***	*	***	*	0.17
CND	***	*	**	*	0.15

Legend:

*** significant at 0.01% level
** significant at 1% level
* significant at 5% level
- not significant (SL is greater than 0.05)

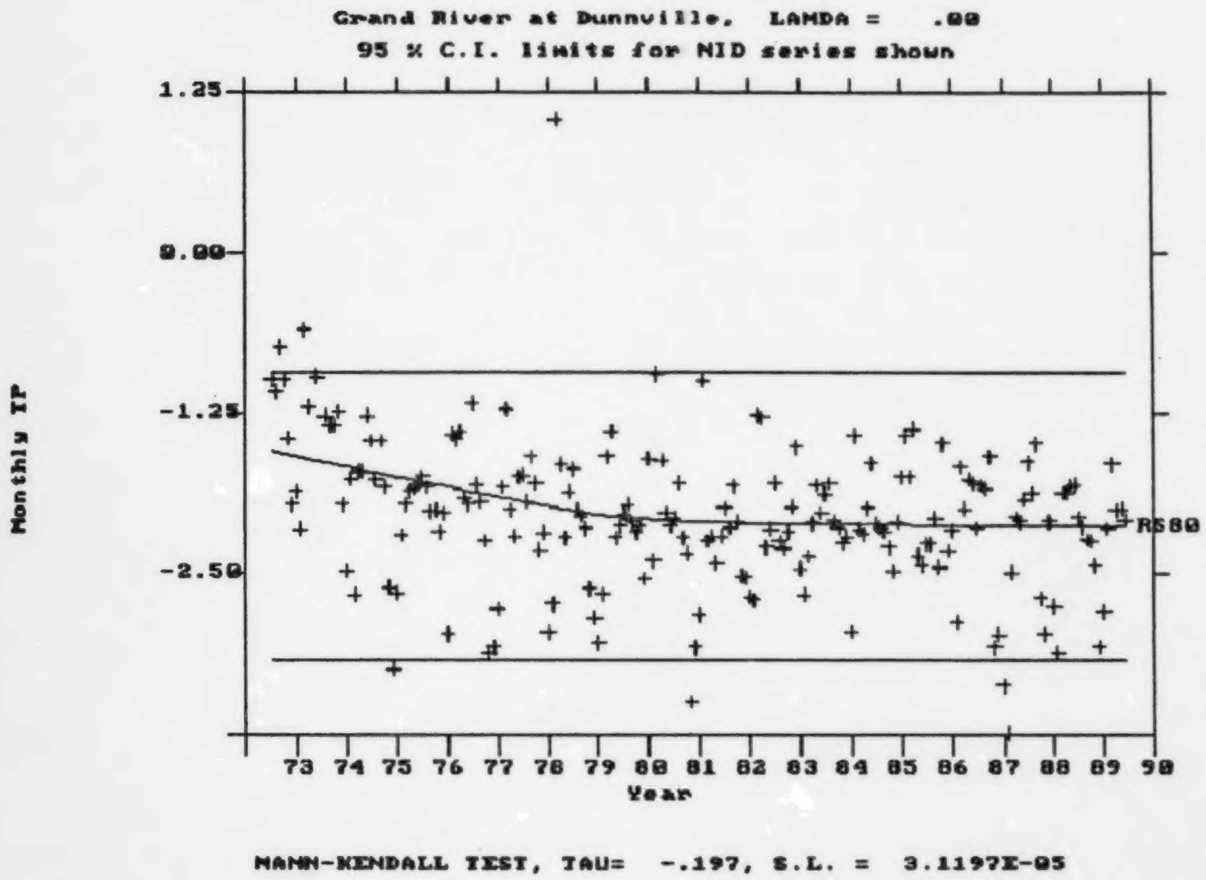

Figure 4.5. Graph of the logarithmic mean monthly TP series against time for the Grand River at Dunnville.

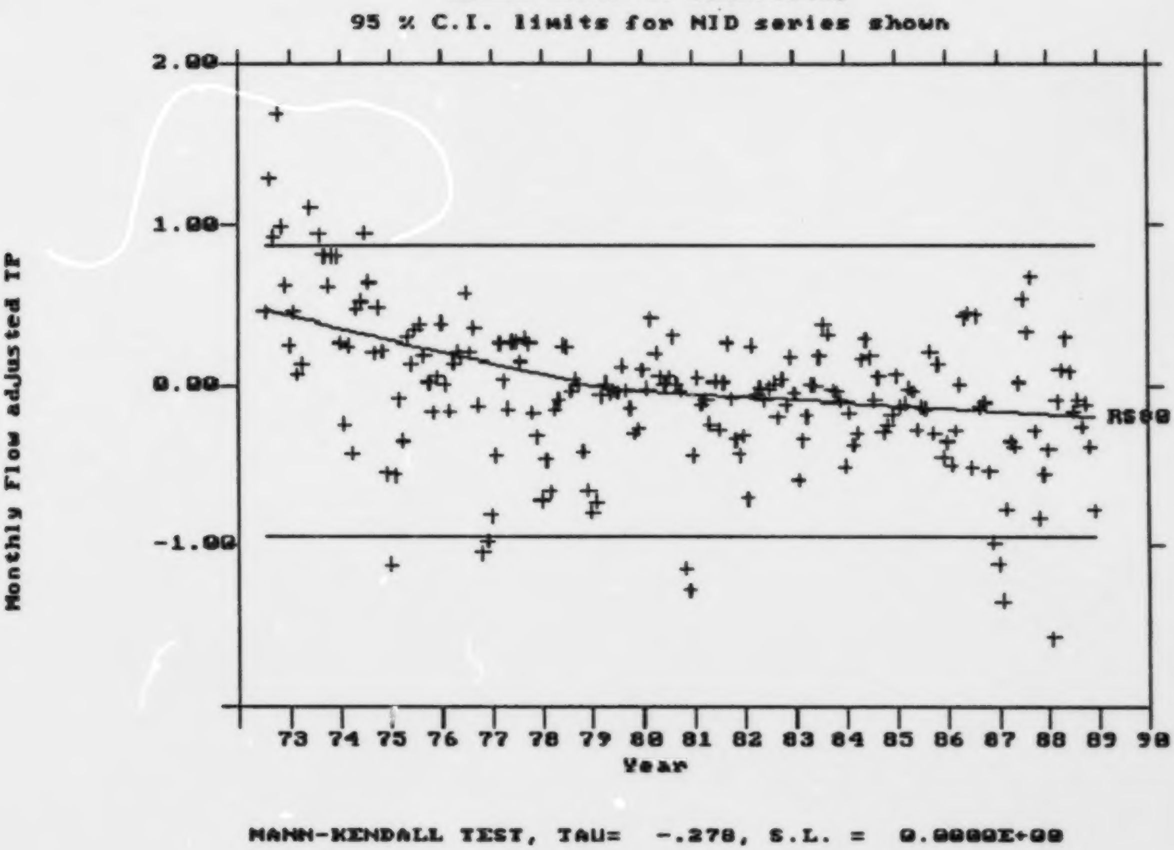

Figure 4.6. Graph of the logarithmic mean monthly flow-adjusted TP series against time for the Grand River at Dunnville.

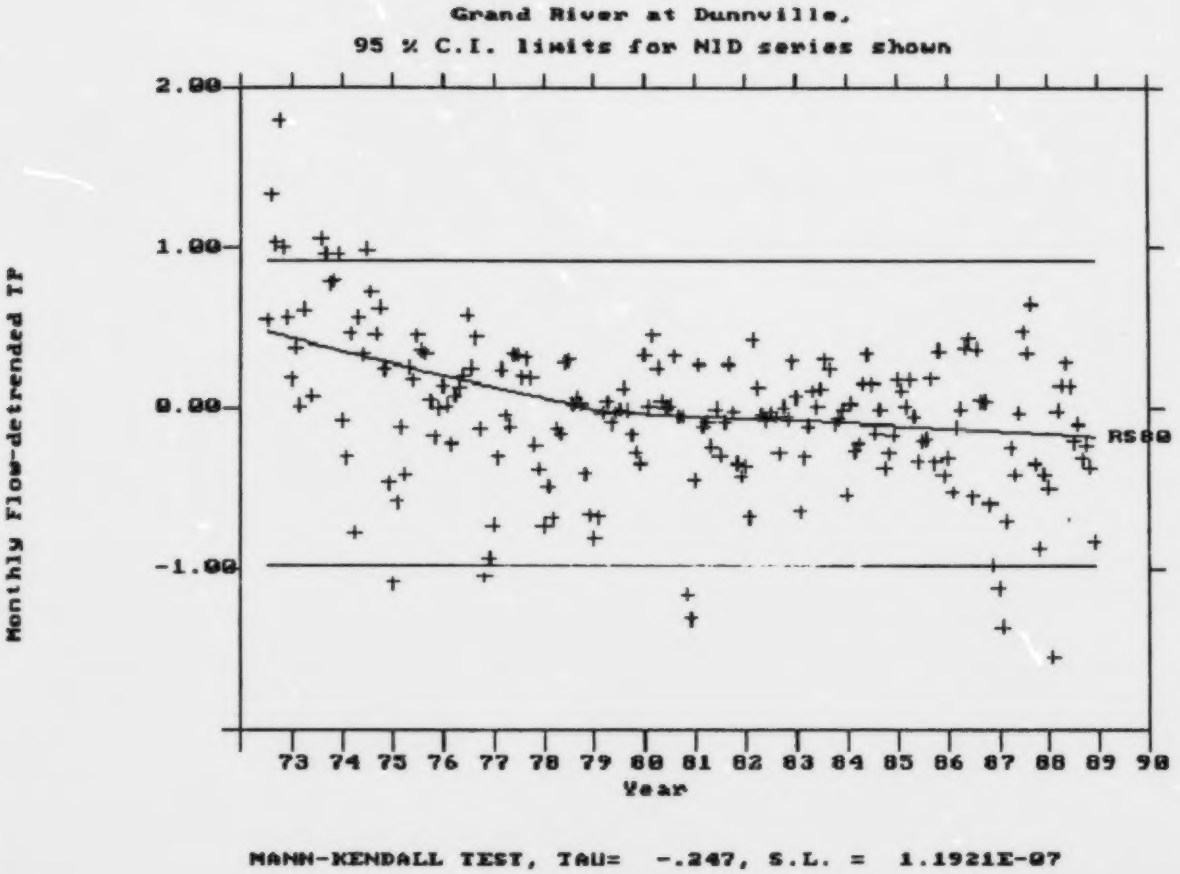

Figure 4.7. Graph of the logarithmic mean monthly detrended-flow-adjusted data for the Grand River at Dunnville.

5. CONCLUSIONS

A flexible and comprehensive trend analysis methodology is now available for detecting trends in water quality data measured in rivers. As described in Section 3, the trend analysis procedure consists of the two main stages of graphical trend studies and trend tests. Specific graphical techniques and statistical trend tests that can be employed in the two main stages are described in detail in Sections 2.2 and 2.3, respectively. A particularly powerful trend test for use with seasonal water quality data is the Spearman partial rank correlation test given in Section 2.3.7. Table 3.2 presents an algorithm for applying the Spearman partial rank correlation trend test when partialling out seasonality. Extensive applications in Section 4 of the trend analysis methodology to water quality series measured in the Saugeen and Grand Rivers demonstrate that the procedure works well in practice.

The overall trend analysis methodology outlined in Table 3.1, contains many original developments in environmental impact assessment. First, the RLWRS of Section 2.2.2 is used for calculating flow-adjusted and detrended-flow-adjusted water quality series. Second, by employing the detrended-flow-adjusted water quality one can eliminate sampling bias, when the entire riverflow series does not possess a trend. As a third contribution, the methodology suggests testing for the presence of seasonality (Section 2.3.6) before applying a seasonal trend test such as the seasonal Mann-Kendall test of Section 2.3.5. Simulation studies show that when the data are not seasonal, the seasonal Mann-Kendall test is not as powerful as the Mann-Kendall trend test (Section 2.3.2). Fourthly, the Spearman partial rank correlation test (Section 2.3.7) when partialling out seasonality provides a powerful test for use with seasonal water quality time series. As noted in Section 2.3.7, the Kendall partial rank correlation test cannot be used for this purpose since the distribution of the test statistic is unknown and probably analytically intractable.

6. ACKNOWLEDGEMENTS

When developing the methodology and testing it using PWQMN data, the authors worked closely with Dr. Byron Bodo from the Ministry of the Environment. He provided thoughtful advice and guidance which contributed significantly to the successful development and application of the trend analysis methodology. The authors greatly appreciate all of Dr. Bodo's valuable assistance as well as support from the Ministry of the Environment.

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8. APPENDIX

DETAILED TREND ANALYSIS RESULTS
FOR
WATER QUALITY TIME SERIES
MEASURED IN THE
SAUGEEN AND GRAND RIVERS

Saugeen.flow

Saugeen River at Burgoyne

Mean Monthly Flow

Table of Contents: Saugeen.flow

(1) Summary and conclusions

(2) Trace and smooth of mean monthly flow

(3) Trend tests on monthly flow data

(4) Box-and-whisker plot of flow-adjusted data

(5) Kruskal-Wallis test for seasonality and seasonal rankings on flow

Summary and Conclusions

Saugeen River - flow

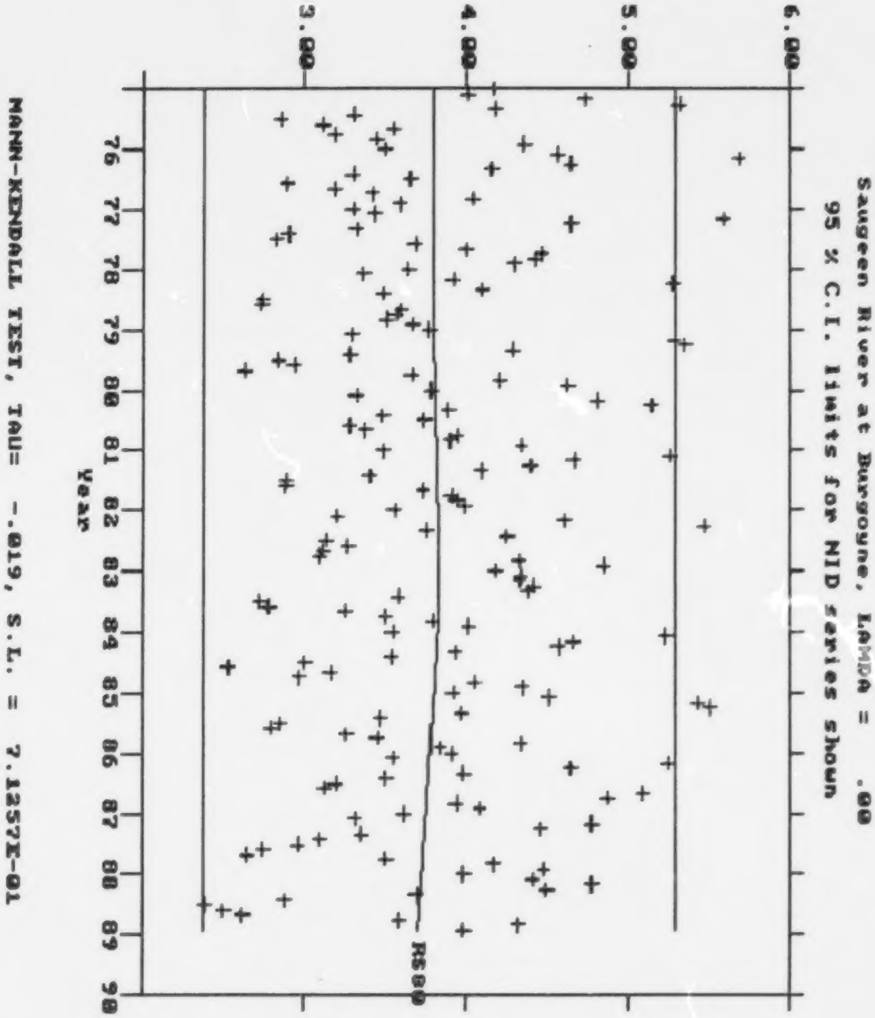
Seasonality: very strong

Outliers: none apparent

Trend: No significant trends detected.

Other:

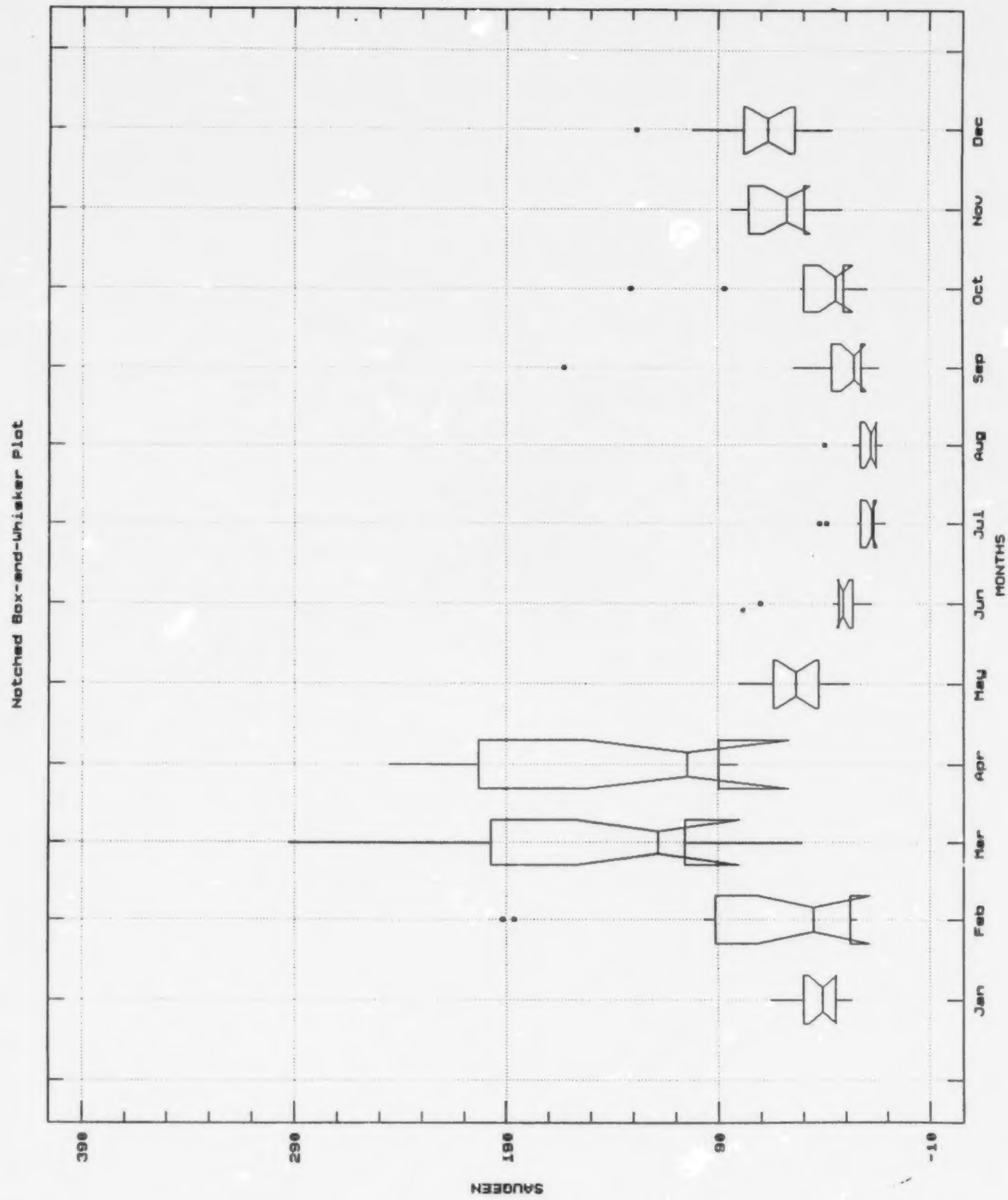
Monthly Flow



Saugeen.FLOW.3

```
    Trend tests for mean monthly data


    Site: Saugeen River at Burgoyne,

    parameter: Mean Monthly Flow

    Basic data - not adjusted for flow


    Mann-Kendall Trend Test
          tau           Significance Level
       -.01910              7.12567E-01


    Ordinary Spearman Trend Test
          rho           Significance Level
       -.03018              6.96499E-01


    Seasonal Mann-Kendall Trend Test
    Score          Variance          Significance Level
     -60.             4004.0                 3.43023E-01


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    4  5  8  8  5  2  1  1  2  3  6  7

         rho           Significance Level
      -.07895              3.07604E-01
```

Saugeen.FLOW.4



SAUGEEN.FLOW.5

```
------------------------------------------------------------
Kruskal-Wallis analysis of SAUGEEN by MONTHS
------------------------------------------------------------
Level             Sample Size     Average Rank
------------------------------------------------------------
  1                   14             81.7857 4
  2                   14             93.0714 5
  3                   14             148.286 8
  4                   14             148.929 8
  5                   14             96.6429 5
  6                   14             53.0000 2
  7                   14             26.4286 1
  8                   14             23.1429 1
  9                   14             51.5714 2
 10                   14             72.9286 3
 11                   14             103.571 6
 12                   14             114.643 7
------------------------------------------------------------
Test statistic = 112.827  Significance level  = 0
```

Saugeen.NHx

Saugeen River at Burgoyne

Ammonia Nitrogen

Summary and Conclusions

Saugeen River - NHx

Data Transformation: logarithmic

Seasonality: not examined

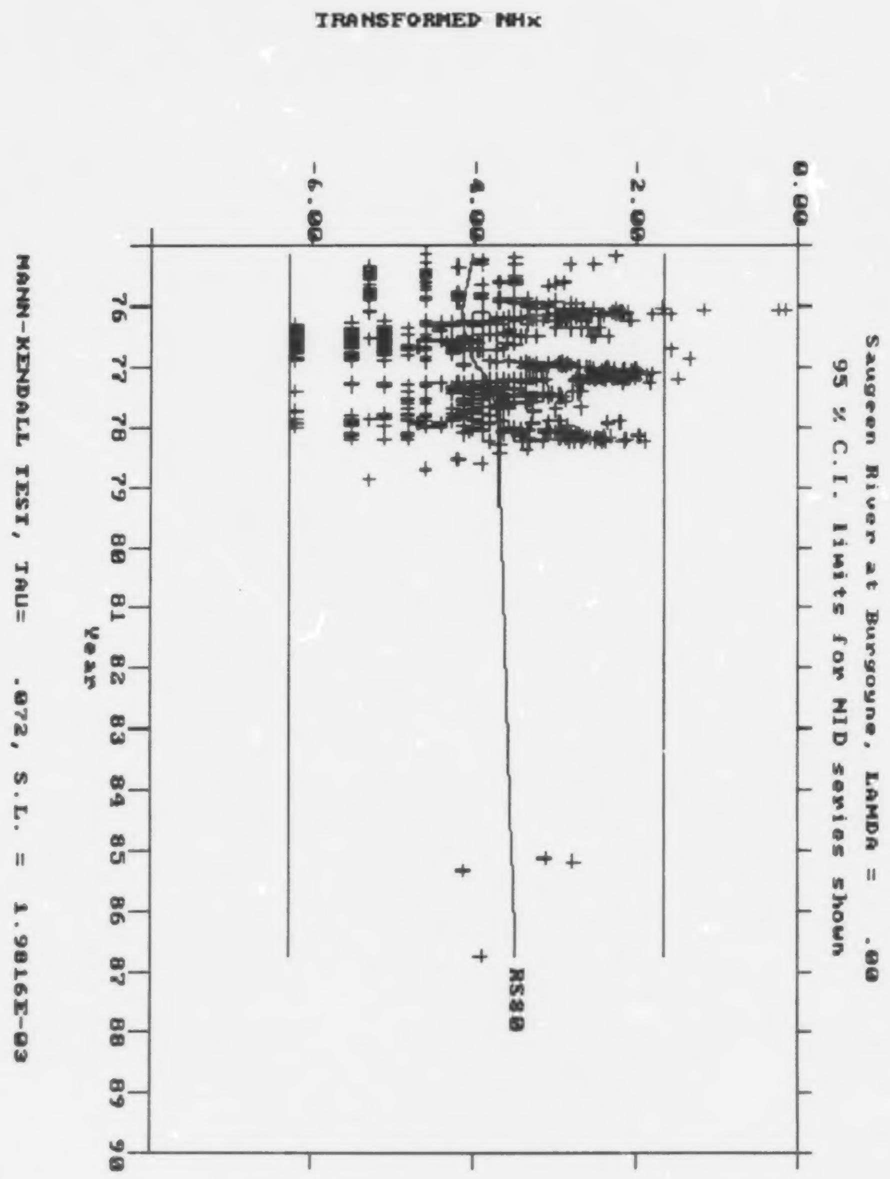
Flow-Concentration Relationship: Positive

Outliers: none apparent

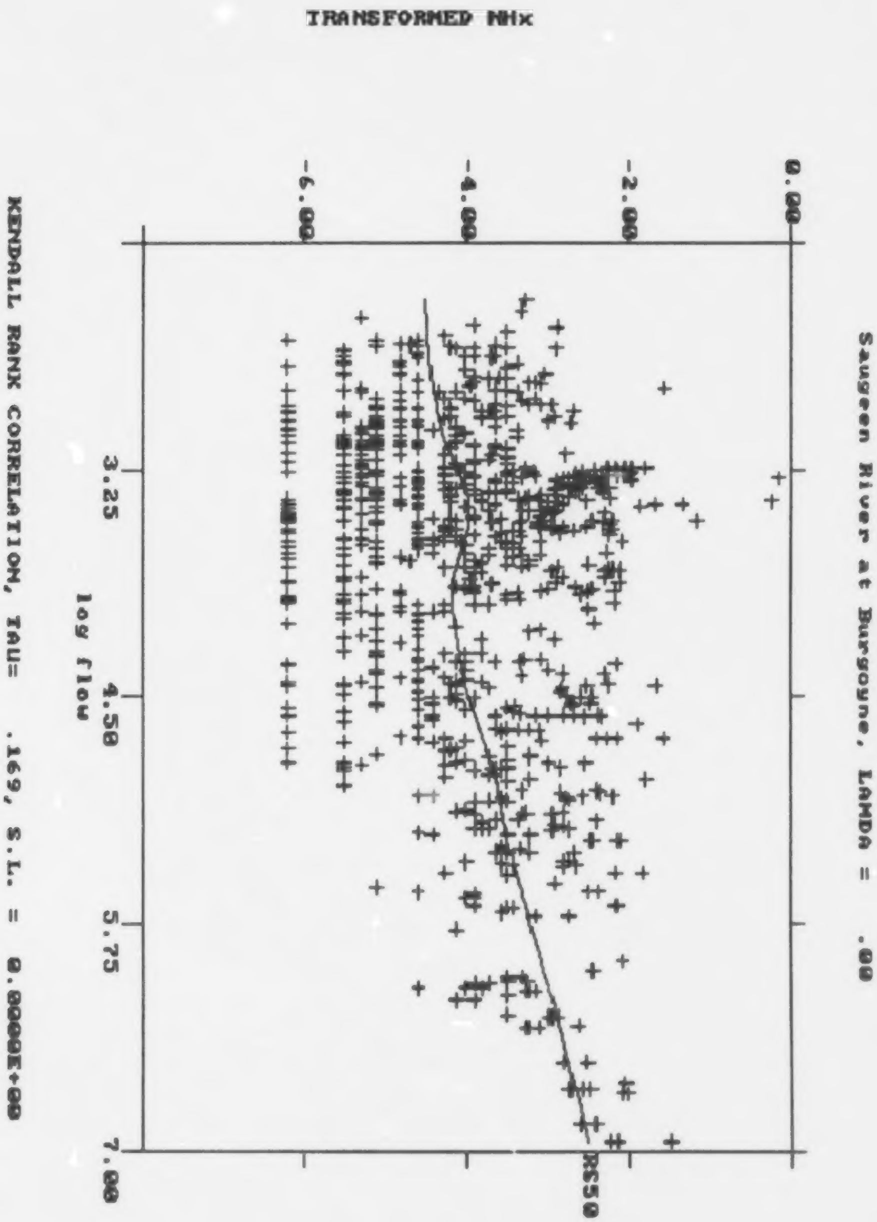
Trend: Insufficient data post 1979 for trend analysis.

Other:

Saugeen.NHX.2



Saugeen.NHX.3



Saugeen.TKN

Saugeen River at Burgoyne

Total Kjeldahl Nitrogen

Table of Contents: Saugeen.TKN

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Scatter and smooth of flow vs NOX

Summary and Conclusions

Saugeen River - TKN

Data Transformation: logarithmic

Seasonality: not examined

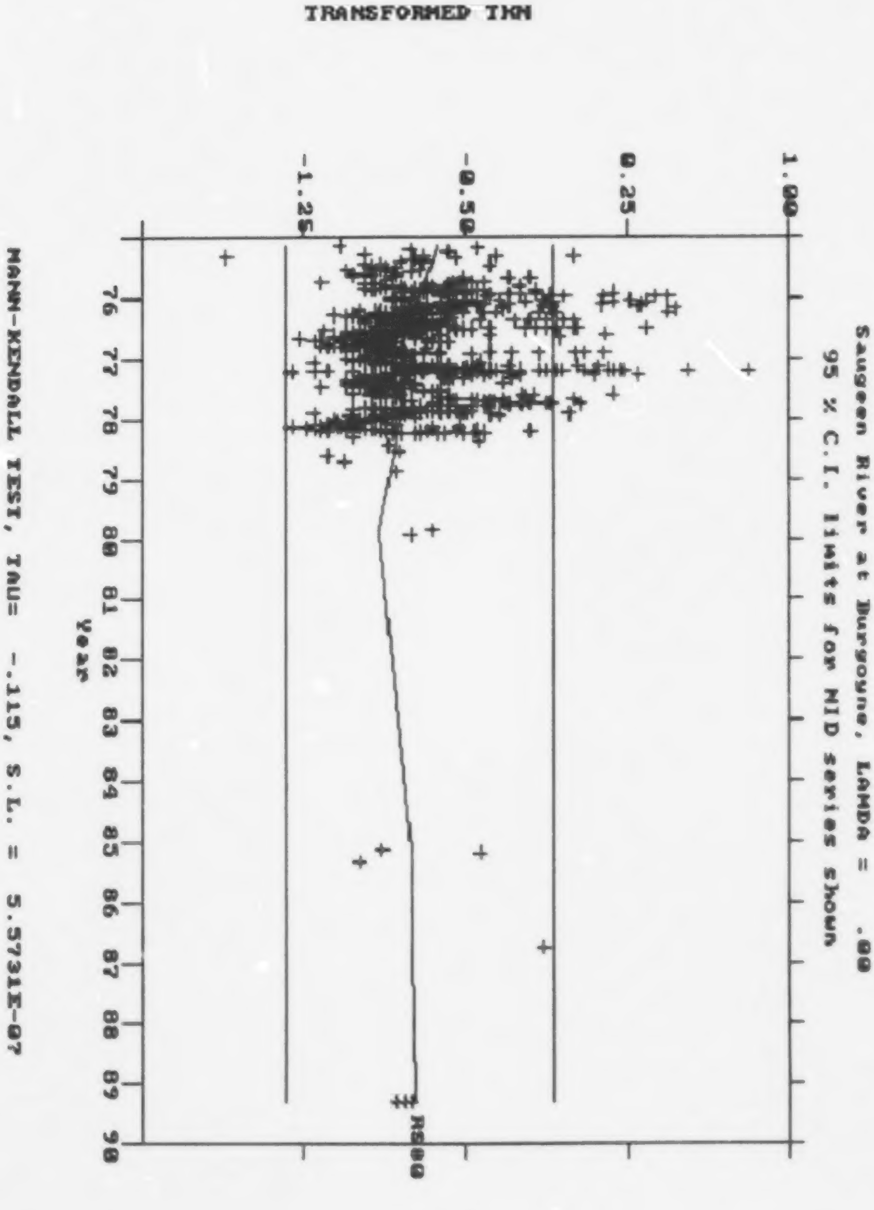
Flow-Concentration Relationship: Positive

Outliers: none apparent

Trend: Insufficient data post 1979 for trend analysis.

Other:

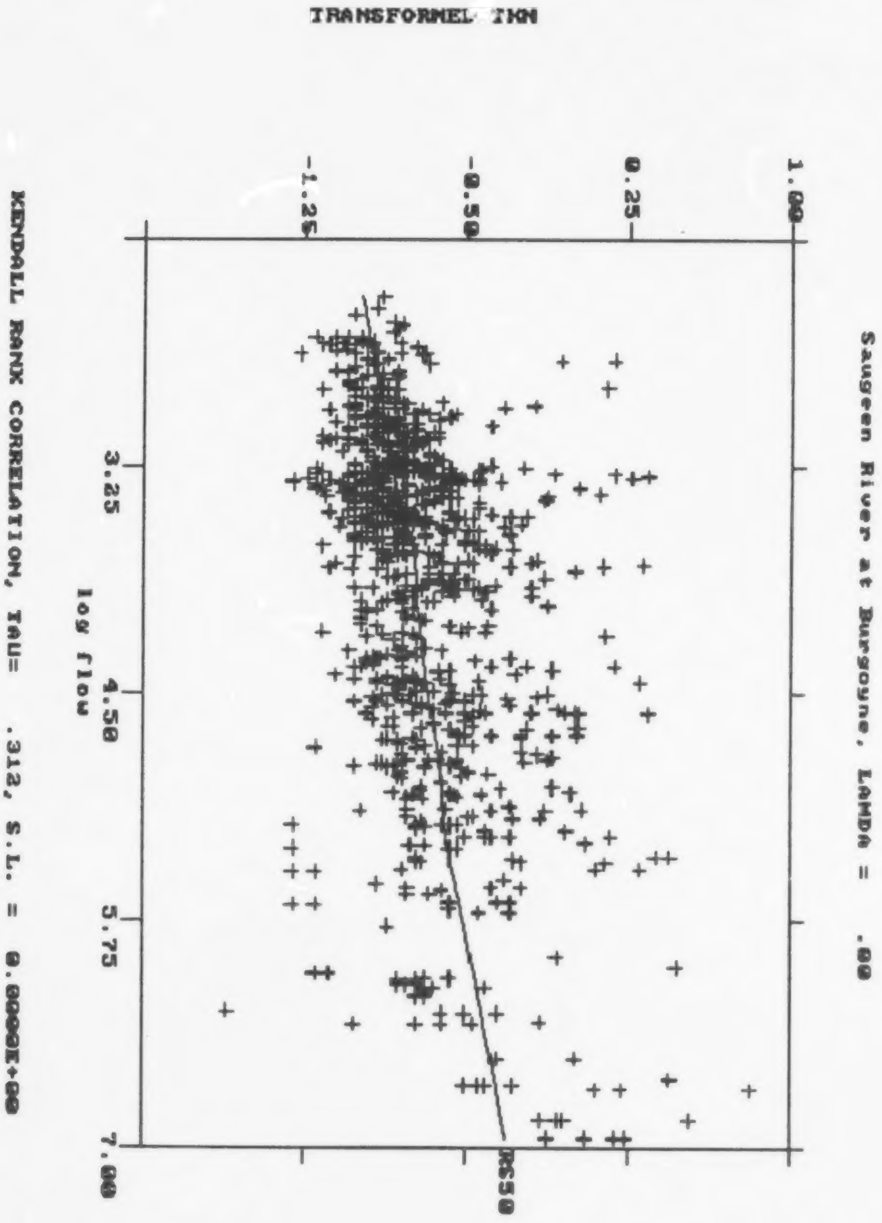
Saugeen.TKN.2


Saugeen River at Burgoyne, LAMDA = .00

95 % C.I. limits for MID series shown

MANN-KENDALL TEST, TAU= -.115, S.L. = 5.5731E-07

Saugeen.TKN.3



Saugeen.NOx

Saugeen River at Burgoyne

Total Nitrates

Table of Contents: Saugeen.NOX

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs NOX

(9) Scatter and smooth of detrended-flow vs NOX

(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box-and-whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Summary and Conclusions

Saugeen River - NOx

Data Transformation: logarithmic

Seasonality: very strong

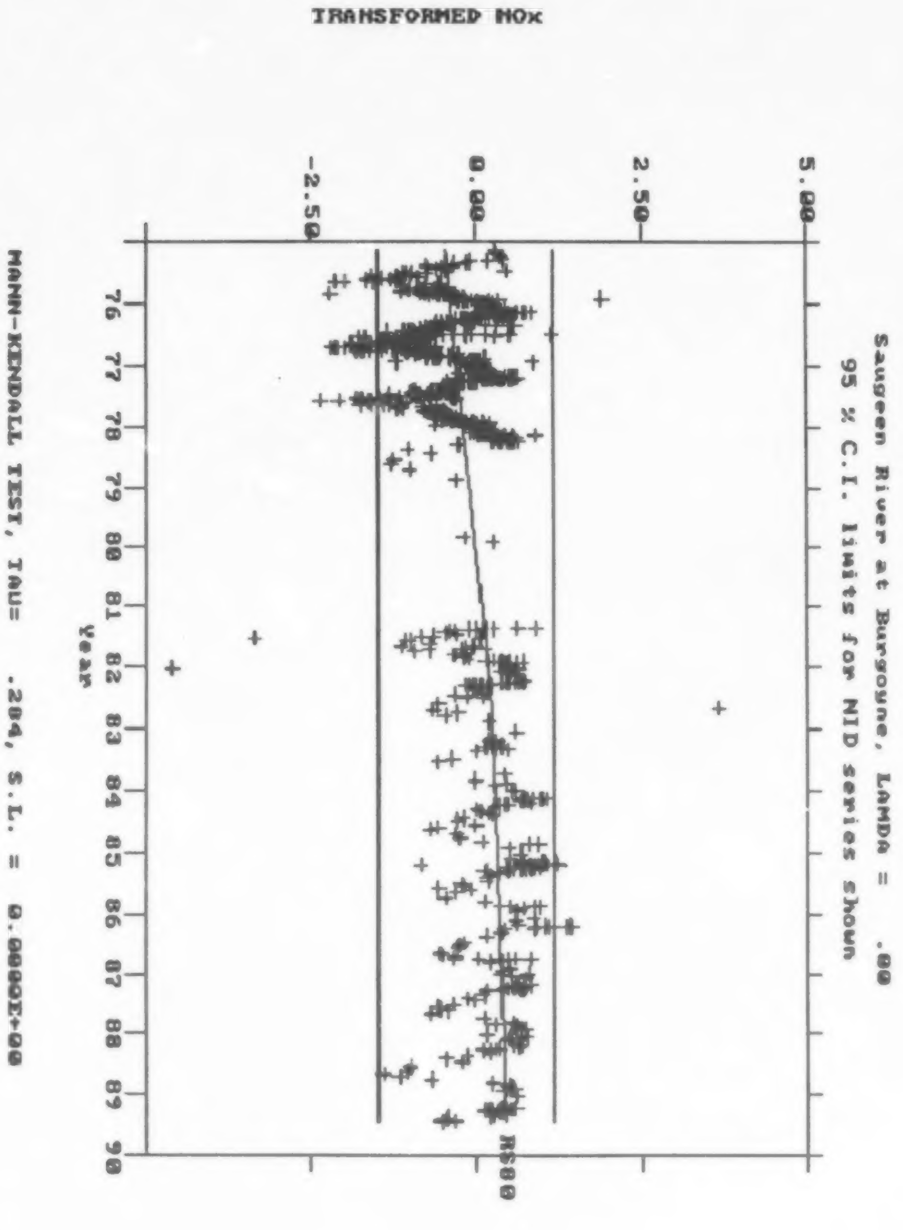
Flow-Concentration Relationship: Positive relationship at low flow with relatively constant relationship at higher flow.

Outliers: none apparent

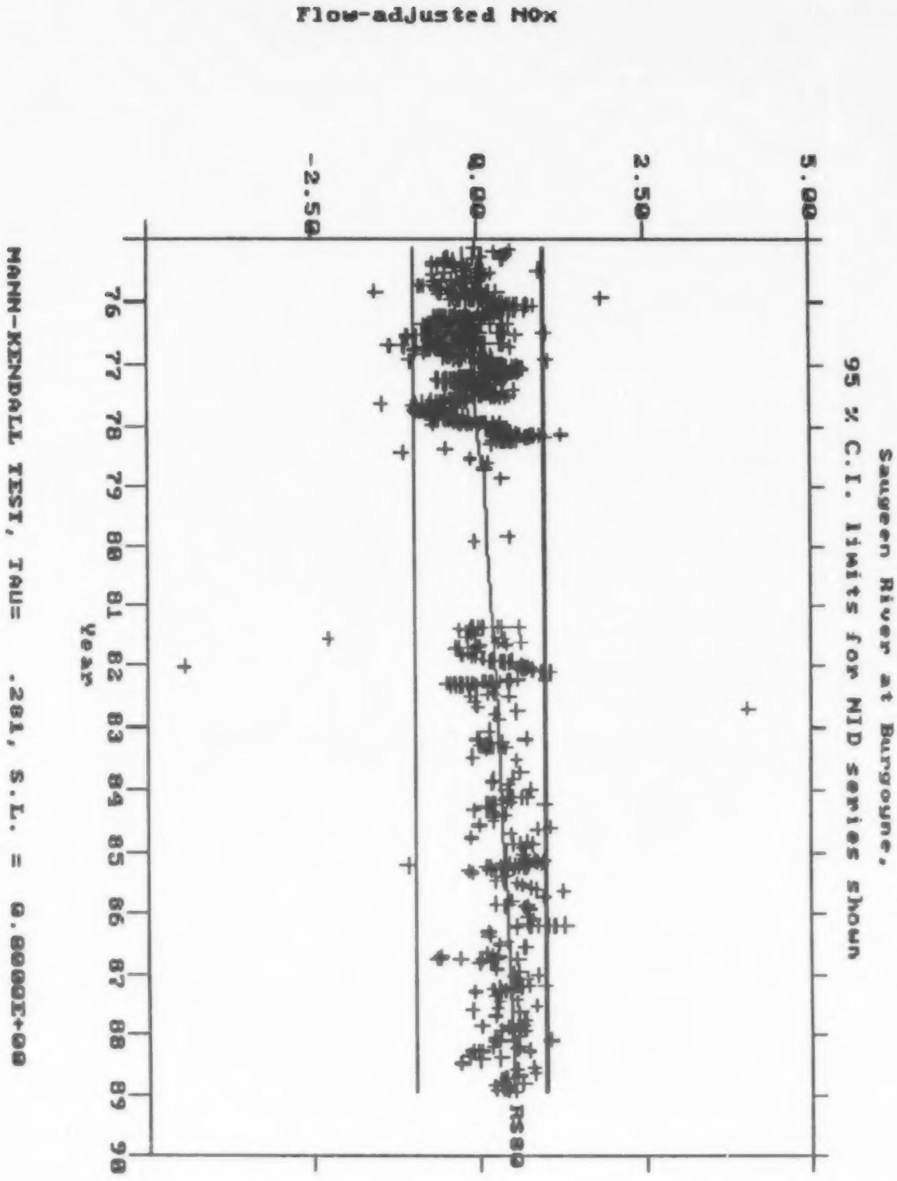
Trend: All tests indicate a significant trend. Examination of the trace plots suggest that it is largely due to a difference in levels in the data from 1975-1978 and 1982-1989..

Other: Very little data over the period 1979-1981.

SAUGEEN.NOX.2



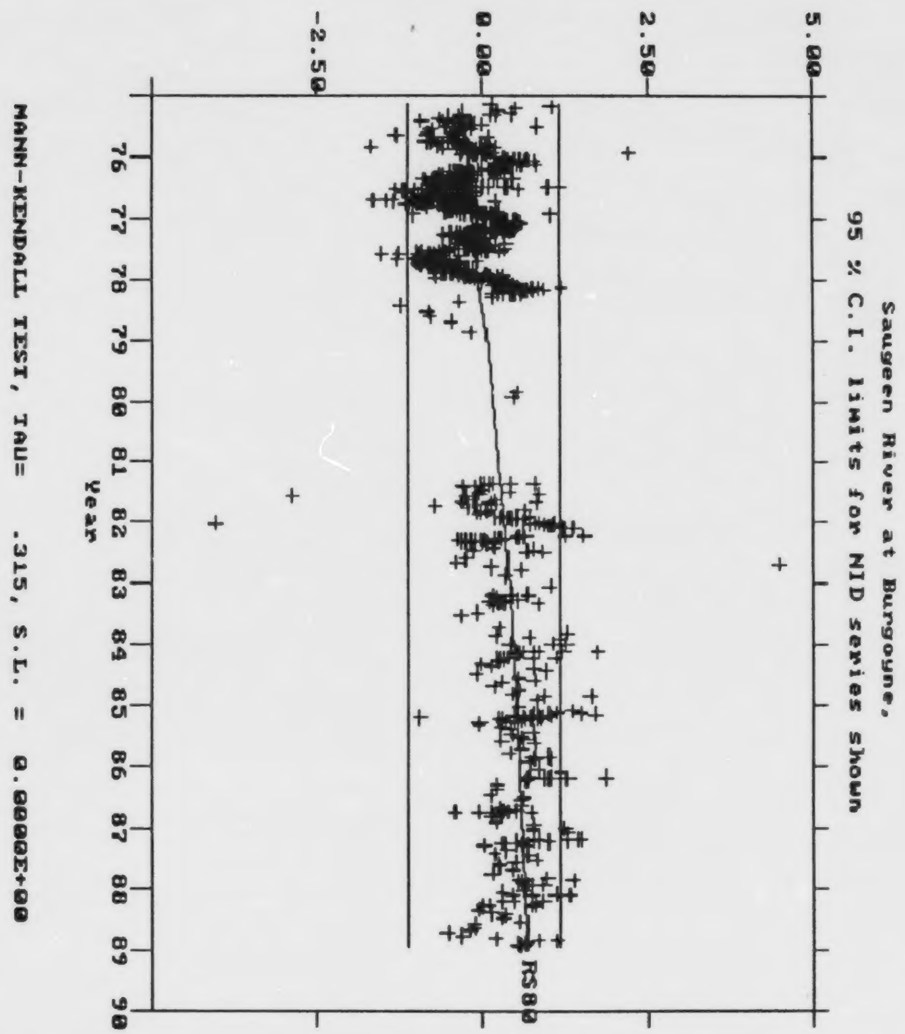
SAUGEEN.NOX.3



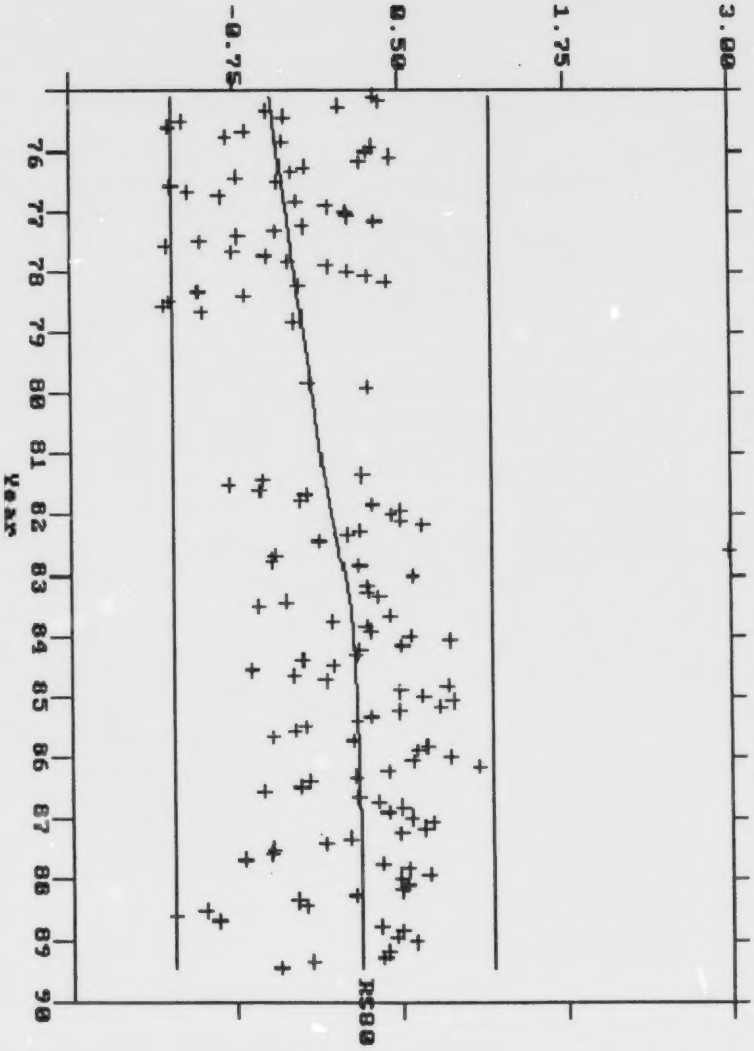
SAUGEEN.NOX.4

Detrended

Flow-adjusted NOx



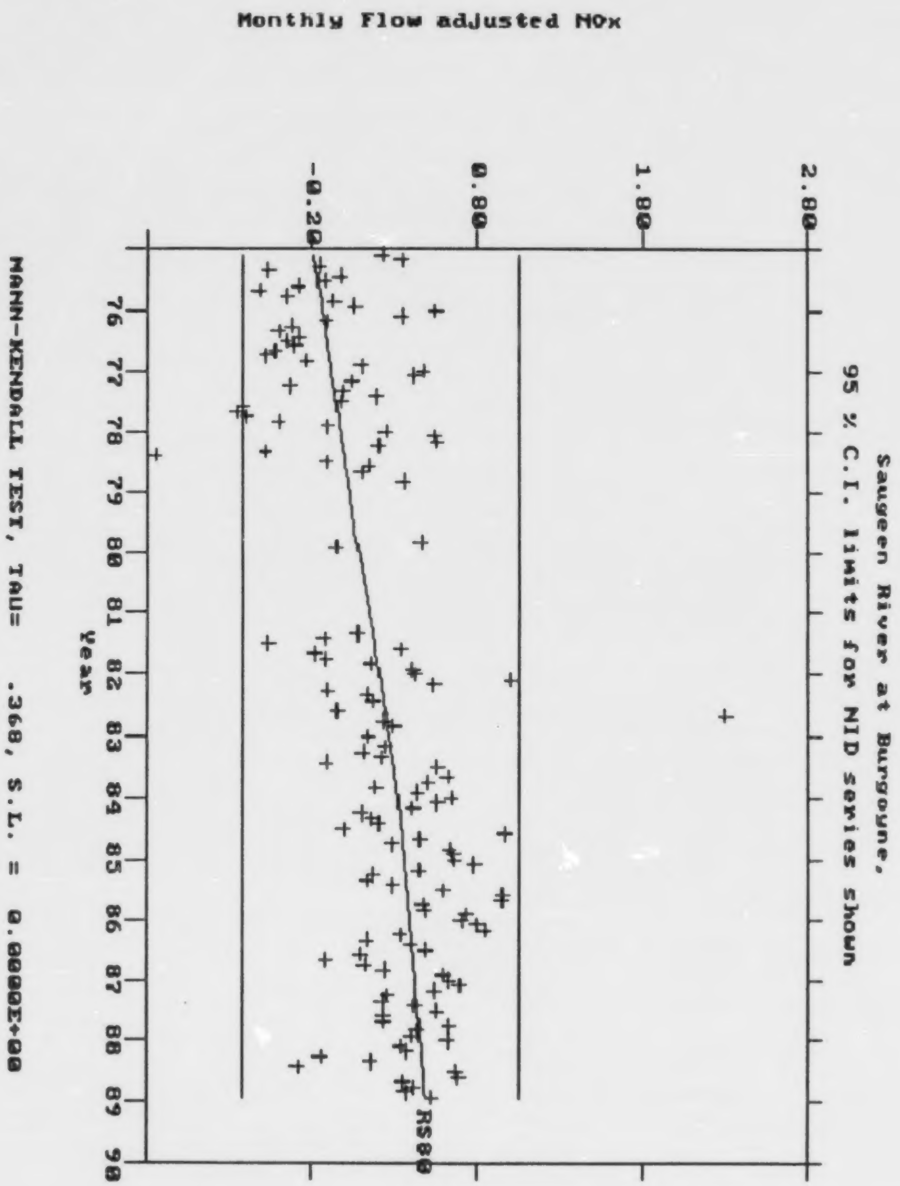
Monthly NOx



Saugeen River at Burgoyne, LAMDA = .00
95 % C.I. limits for NID series shown

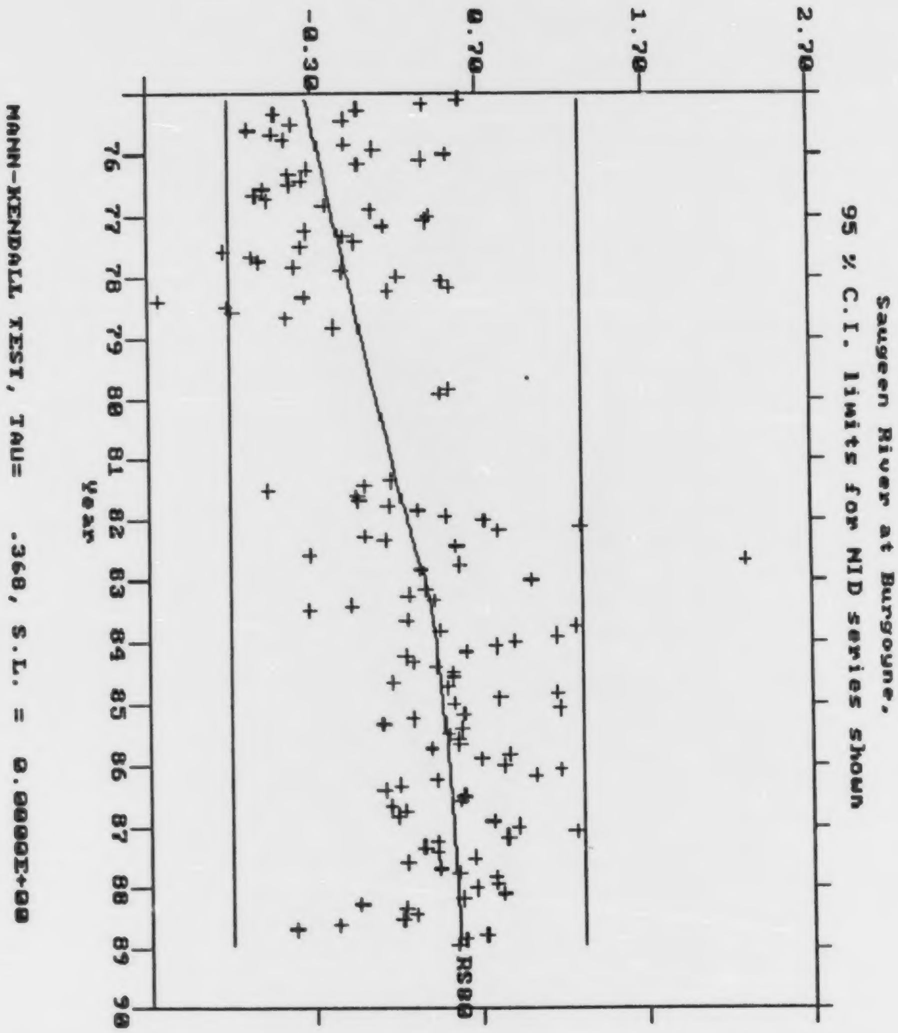
MANN-KENDALL TEST, TAU= .244, S.L. = 1.8835E-05

SAUGEEN.NOX.6

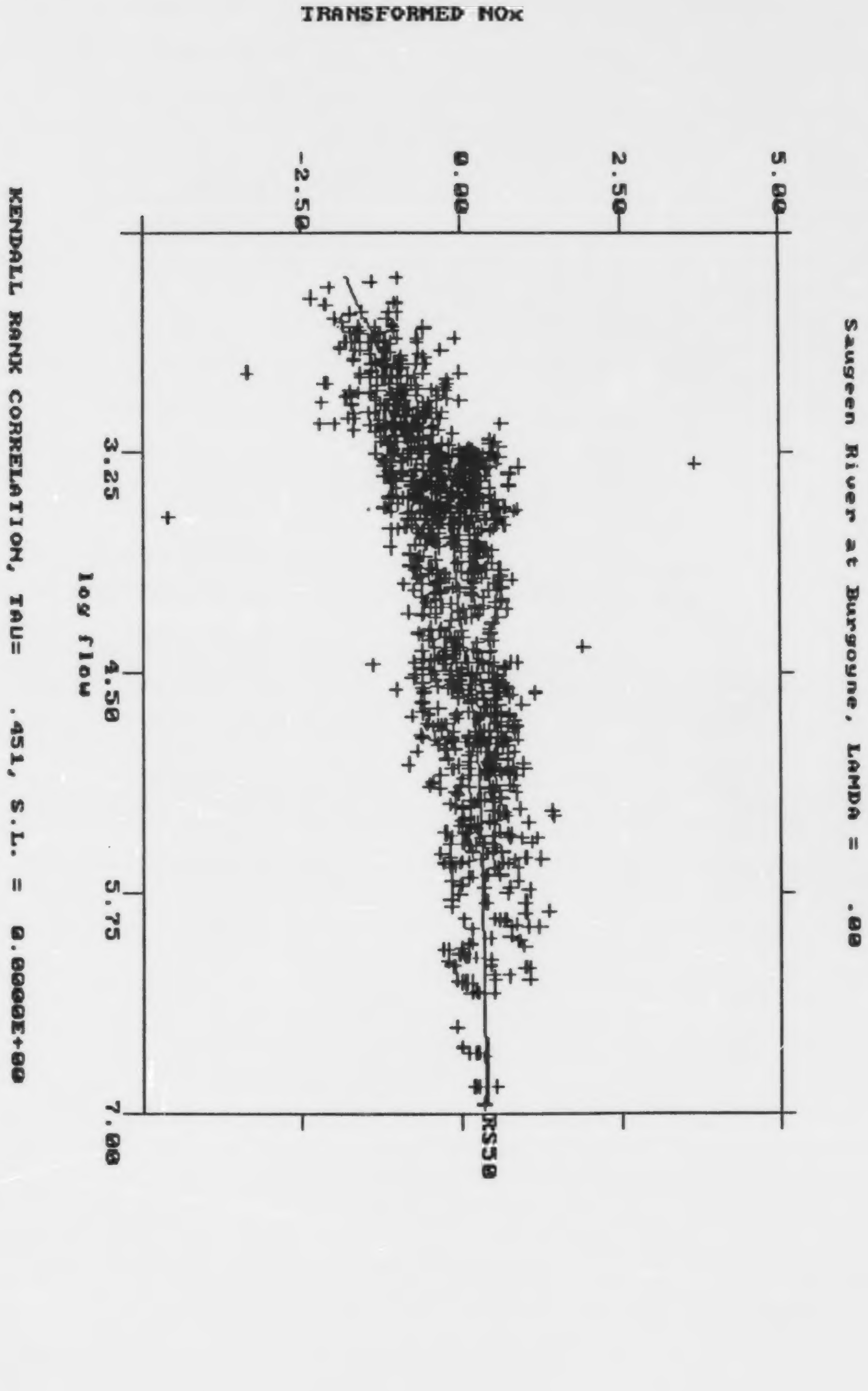


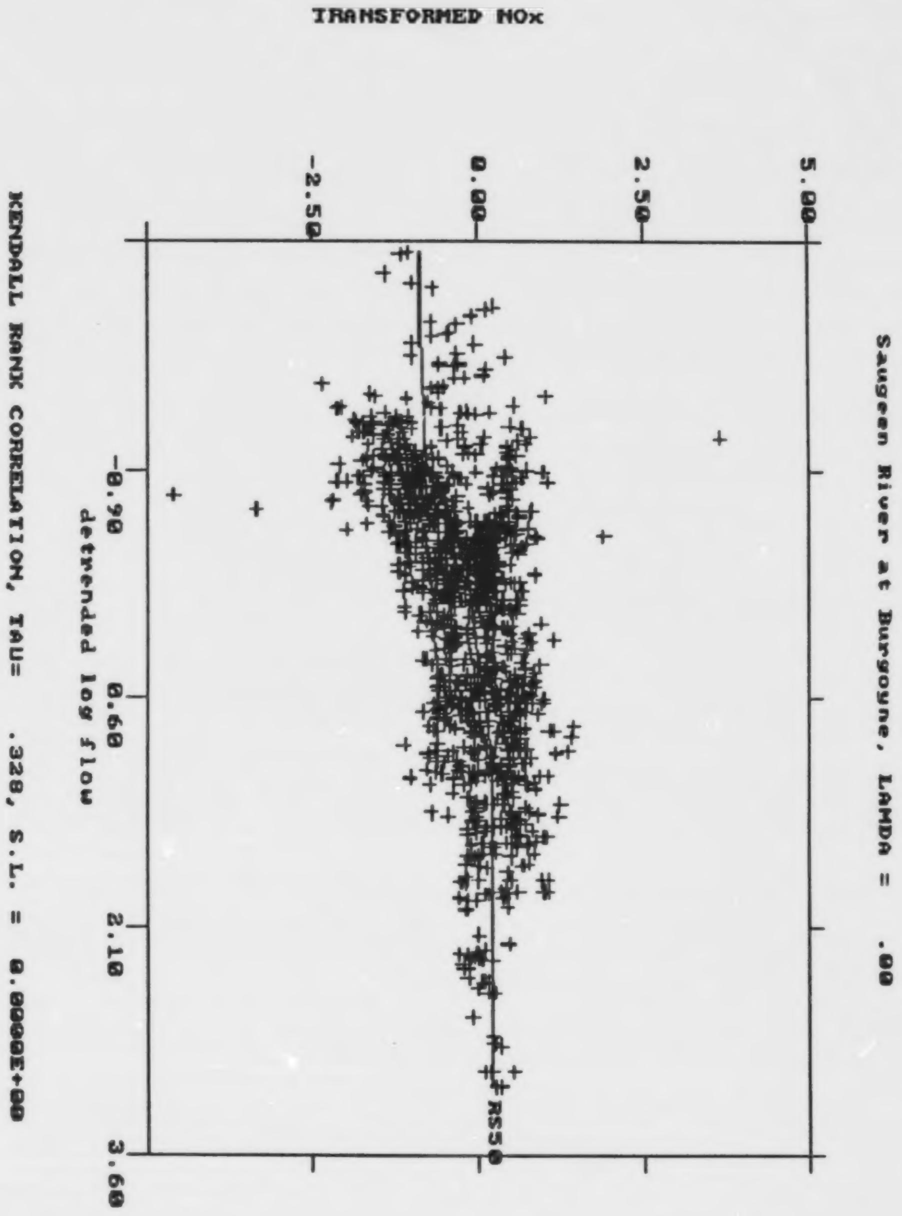
SAUGEEN.NOX.7

Monthly Flow-detrended NOx



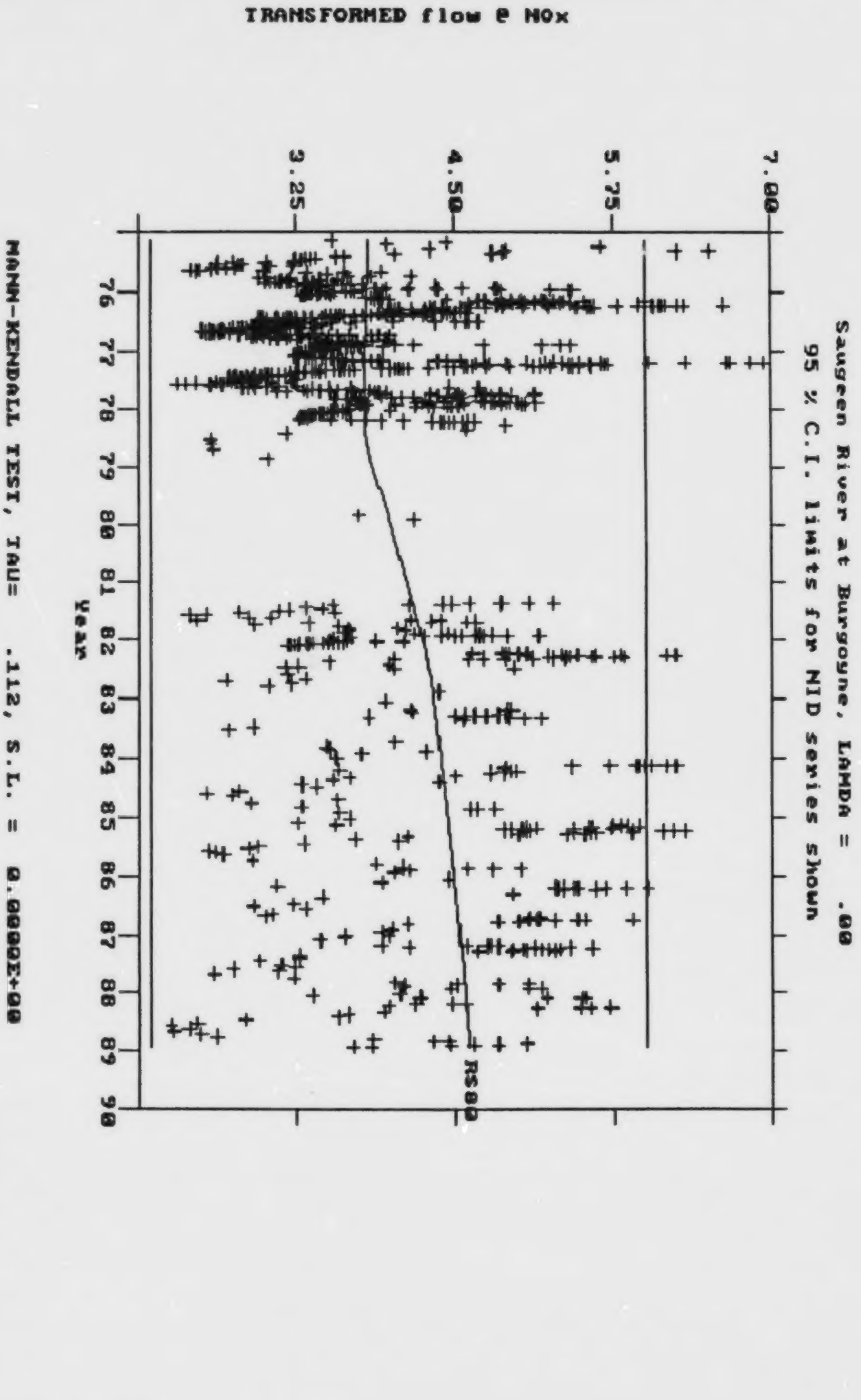
SAUGEEN.NOX.8





KENDALL RANK CORRELATION, TAU= .328, S.L. = 0.0000E+00

SAUGEEN.NOX.10



SAUGEEN.NOX.11

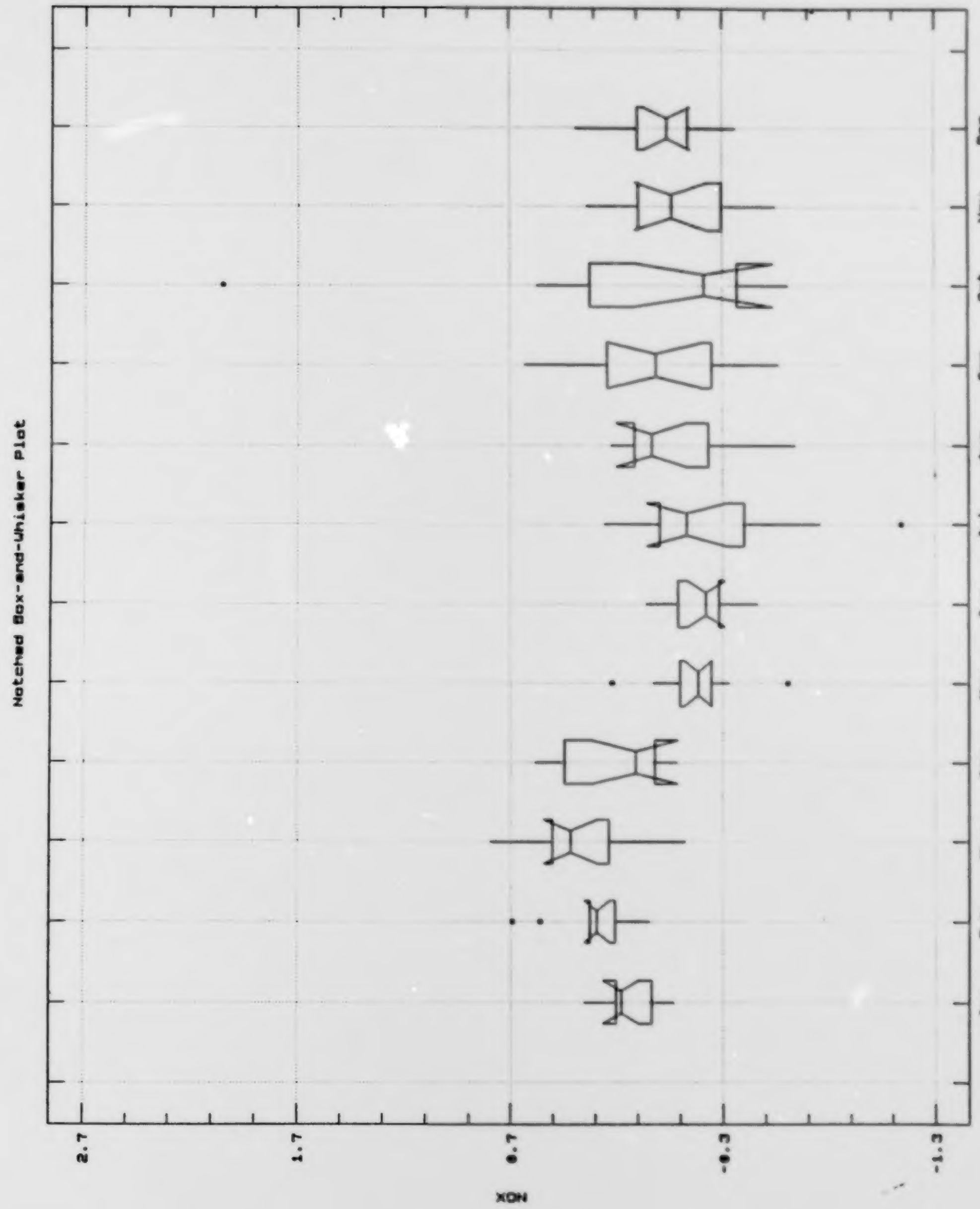
```
Trend tests for mean monthly data


Site: Saugeen River at Burgoyne,

parameter: NOx

Basic data - not adjusted for flow


Mann-Kendall Trend Test
      tau             Significance Level
    .24427                 1.88351E-05


Ordinary Spearman Trend Test
      rho             Significance Level
    .36977                 1.29938E-05


Seasonal Mann-Kendall Trend Test
Score           Variance               Significance Level
 326.              2394.0                        0.00000E+00


Spearman Trend Test Partialling Out Seasonality

Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    8  8 10  9  7  6  4  2  1  3  5  7

     rho             Significance Level
   .47567                 0.00000E+00
```

SAUGEEN.NOX.12

```
----------------------------------------------------------------------
Kruskal-Wallis analysis of NOX by NOXMON
----------------------------------------------------------------------
Level        Sample Size    Average Rank
----------------------------------------------------------------------
 1              11          100.000  8
 2              10          103.900  8
 3              12          121.500  10
 4              12          115.750  9
 5              13          84.3077  7
 6              13          58.1538  6
 7              11          41.5455  4
 8              11          27.2727  2
 9              12          23.4167  1
10               11          34.8182  3
11               13          48.6923  5
12              11           88.9091  7
----------------------------------------------------------------------
Test statistic = 98.0336  Significance level  = 4.44089E-16
```

```
    Trend tests for mean monthly data

    Site: Saugeen River at Burgoyne,

    parameter: NOx

    Flow-adjusted Data

    Mann-Kendall Trend Test
          tau          Significance Level
        .36761              0.00000E+00

    Ordinary Spearman Trend Test
          rho          Significance Level
        .54166              0.00000E+00

    Seasonal Mann-Kendall Trend Test
    Score          Variance         Significance Level
     314.             2146.7                0.00000E+00

    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    6  7  7  6  2  1  2  4  5  3  3  4

         rho          Significance Level
       .57163              0.00000E+00
```

SAUGEEN.NOX.14



SAUGEEN.NOX.15

```
------------------------------------------------------------
Kruskal-Wallis analysis of NOX by NOXMON
------------------------------------------------------------
Level            Sample Size     Average Rank
------------------------------------------------------------
  1                  10             89.5000 6
  2                  10             107.700 7
  3                  11             107.364 7
  4                  11             92.2727 6
  5                  12             42.0000 1
  6                  12             37.1667 1
  7                  11             46.1818 2
  8                  11             60.8182 4
  9                  12             68.3333 5
 10                  11             54.3636 3
 11                  13             57.9231 3
 12                  11             64.9091 4
------------------------------------------------------------
Test statistic = 47.5194  Significance level  = 1.73872E-6
```

SAUGEEN.NOX.16

```
Trend tests for mean monthly data

Site: Saugeen River at Burgoyne,

parameter: NOx

Flow-adjusted Data


Mann-Kendall Trend Test
      tau           Significance Level
    .36783                0.00000E+00


Ordinary Spearman Trend Test
      rho           Significance Level
    .54818                0.00000E+00


Seasonal Mann-Kendall Trend Test
Score           Variance          Significance Level
 338.             2146.7                     0.00000E+00


Spearman Trend Test Partialling Out Seasonality

Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    6  7  8  7  4  2  3  3  1  2  4  5

     rho           Significance Level
   .60612                0.00000E+00
```

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of NOX by NOXMON
--------------------------------------------------------------------------------
Level          Sample Size    Average Rank
--------------------------------------------------------------------------------
  1               10           95.9000   6
  2               10          103.300    7
  3               11          122.545    8
  4               11          100.000    7
  5               12           58.3333   4
  6               12           43.3333   2
  7               11           48.0909   3
  8               11           51.7273   3
  9               12           30.0000   1
 10               11           41.8182   2
 11               13           56.6923   4
 12               11           78.6364   5
--------------------------------------------------------------------------------
Test statistic = 70.3967  Significance level  = 1.0269E-10
```

Saugeen.FRP

Saugeen River at Burgoyne

Filtered Reactive Phosphorus

Table of Contents: Saugeen.FRP

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs FRP

(9) Scatter and smooth of detrended-flow vs FRP

(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box-and-whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Summary and Conclusions

Saugeen River - FRP

Data Transformation: logarithmic

Seasonality: very strong

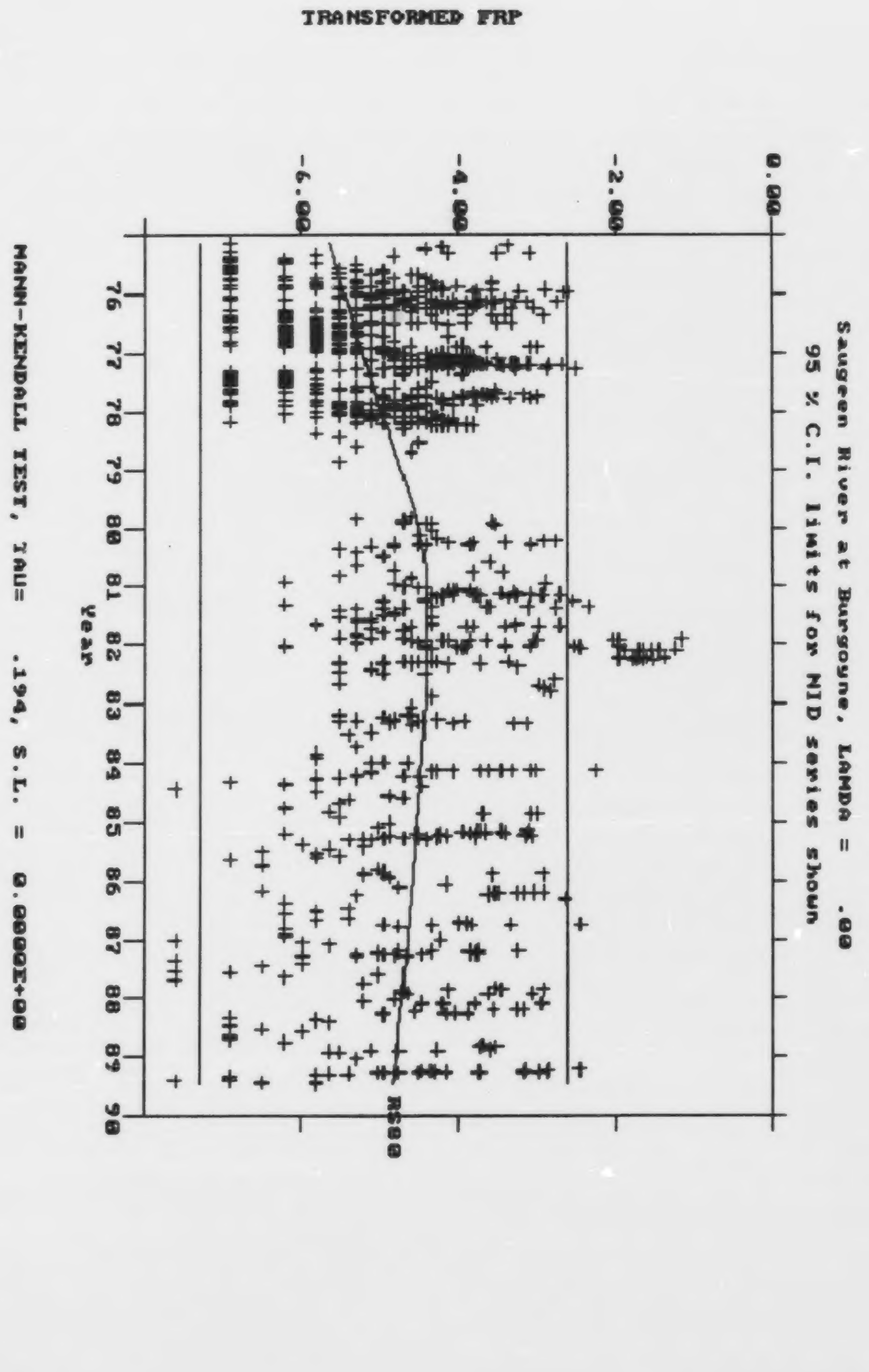
Flow-Concentration Relationship: Positive

Outliers: none apparent

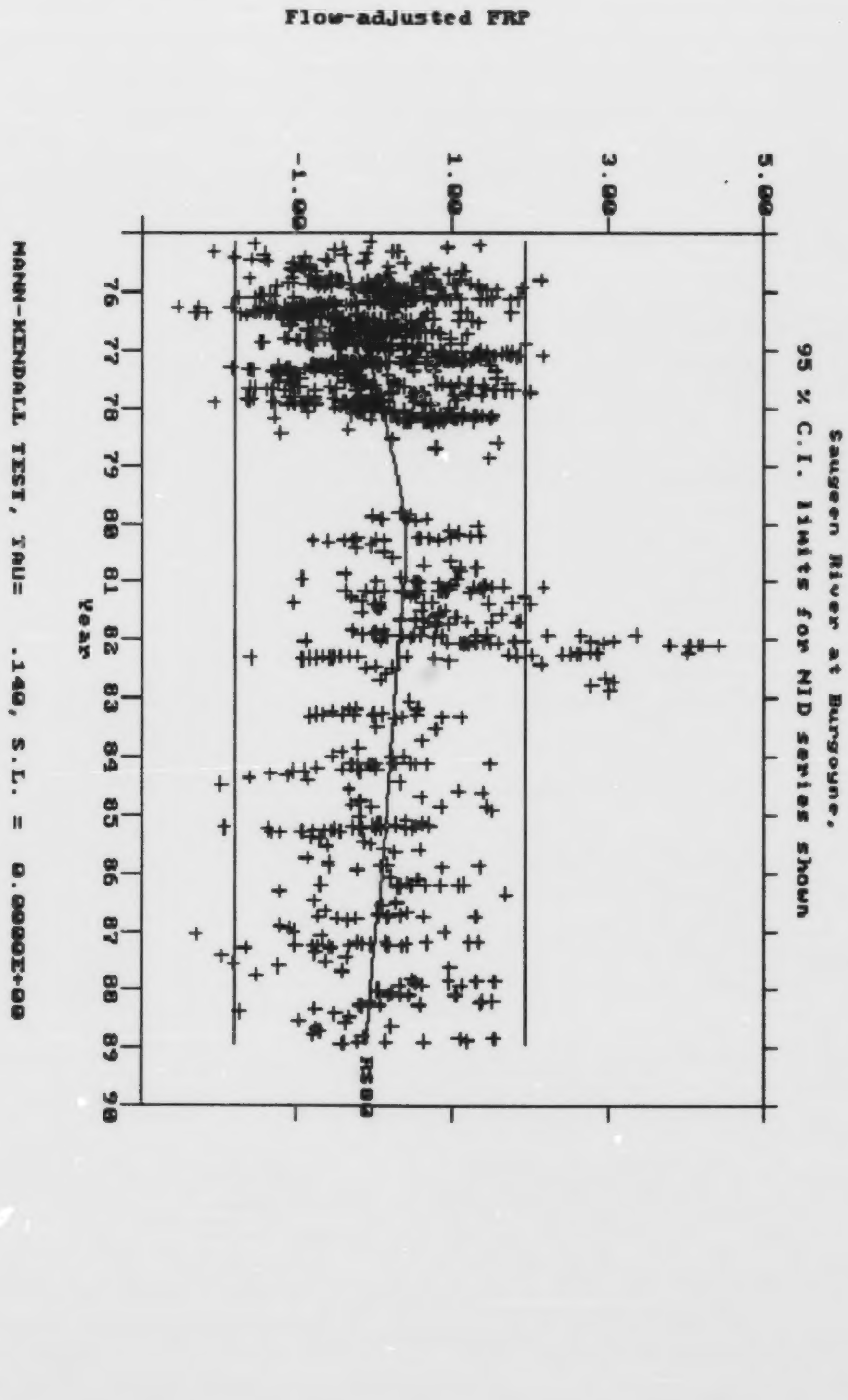
Trend: Trend tests not significant. Plots of full data set suggest that there may have been a pulse-like change during 1980-1983..

Other:

Saugeen.FRP.2



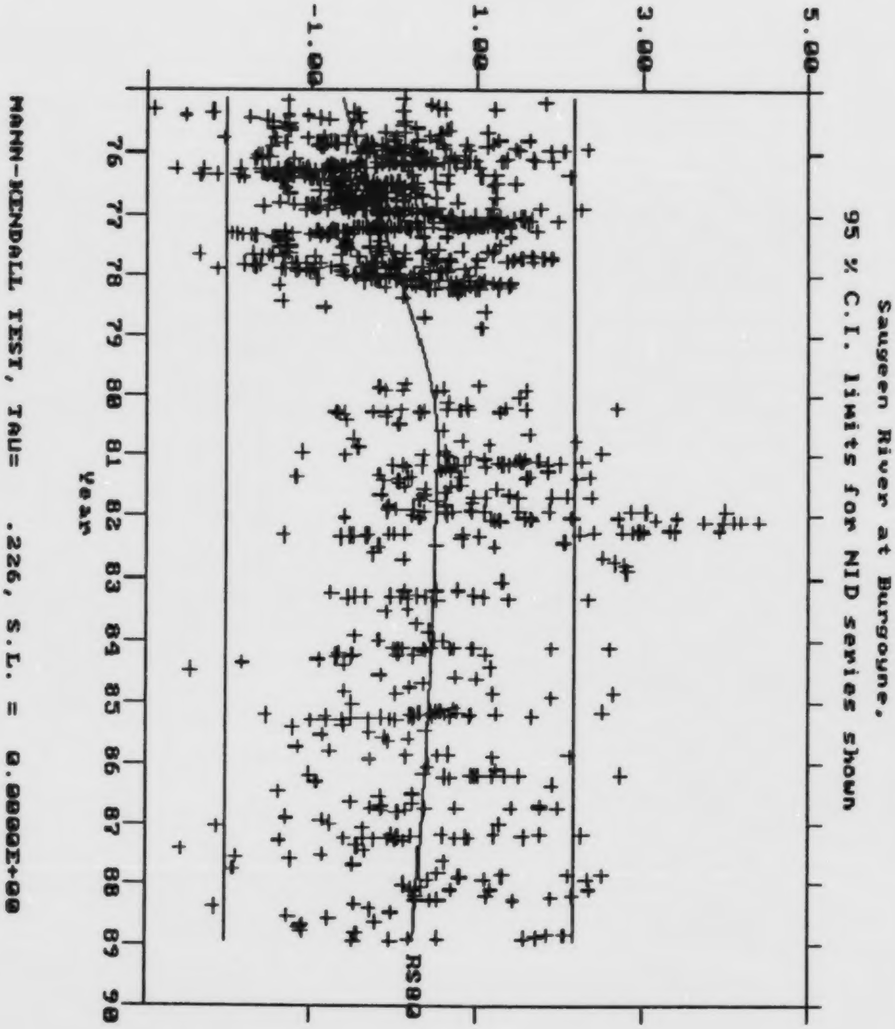
Saugeen.FRP.3



Saugeen.FRP.4

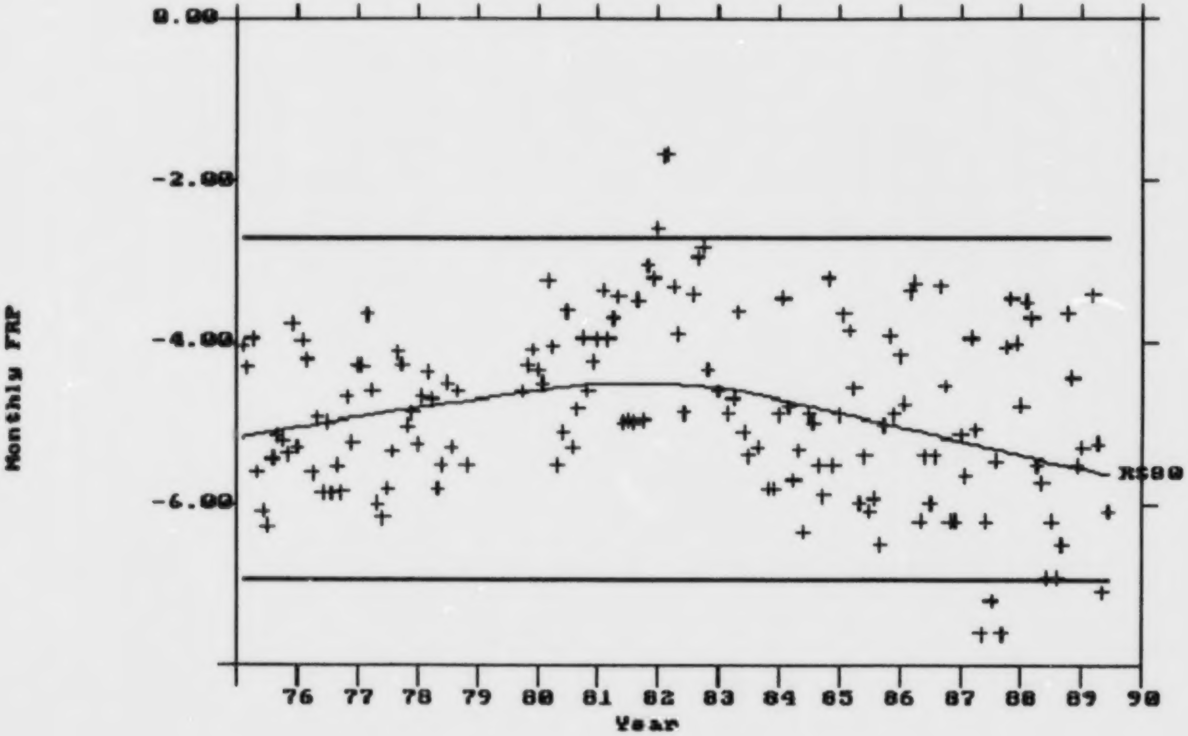
Detrended

Flow-adjusted FRP



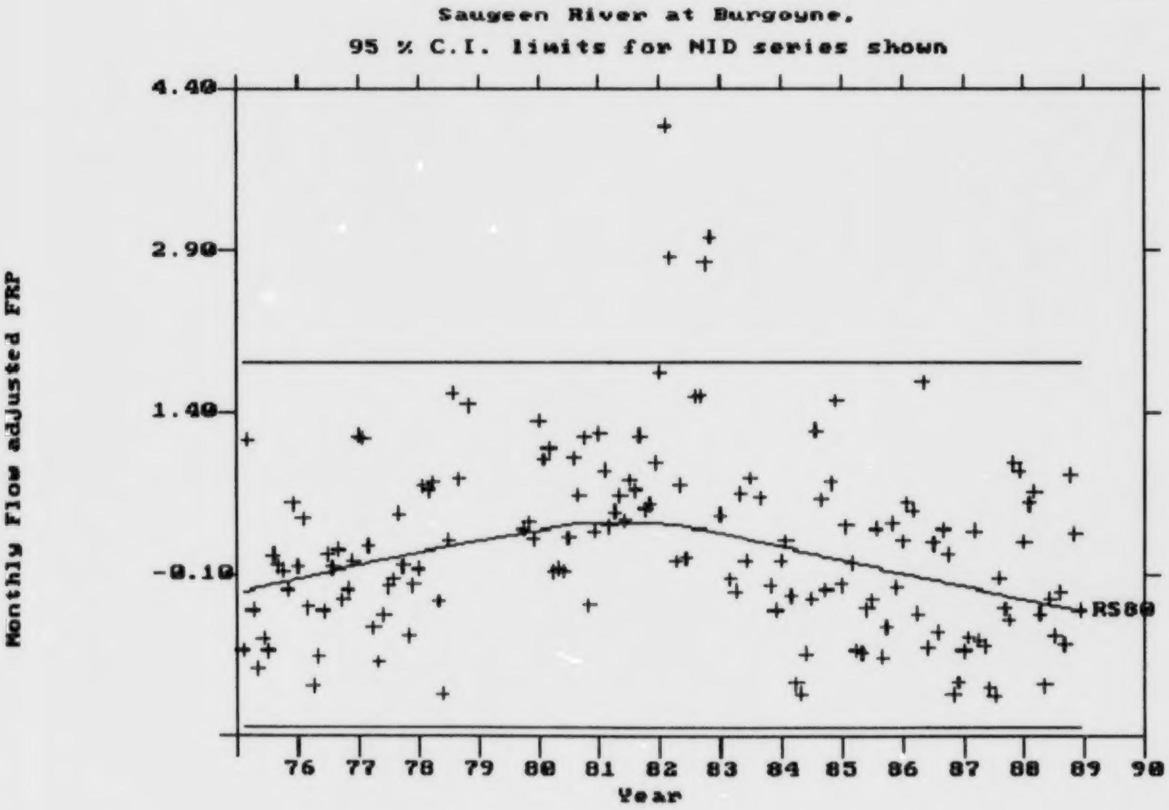
Saugeen.FRP.5

Saugeen River at Burgoyne, LAMDA = .00
95 % C.I. limits for NID series shown



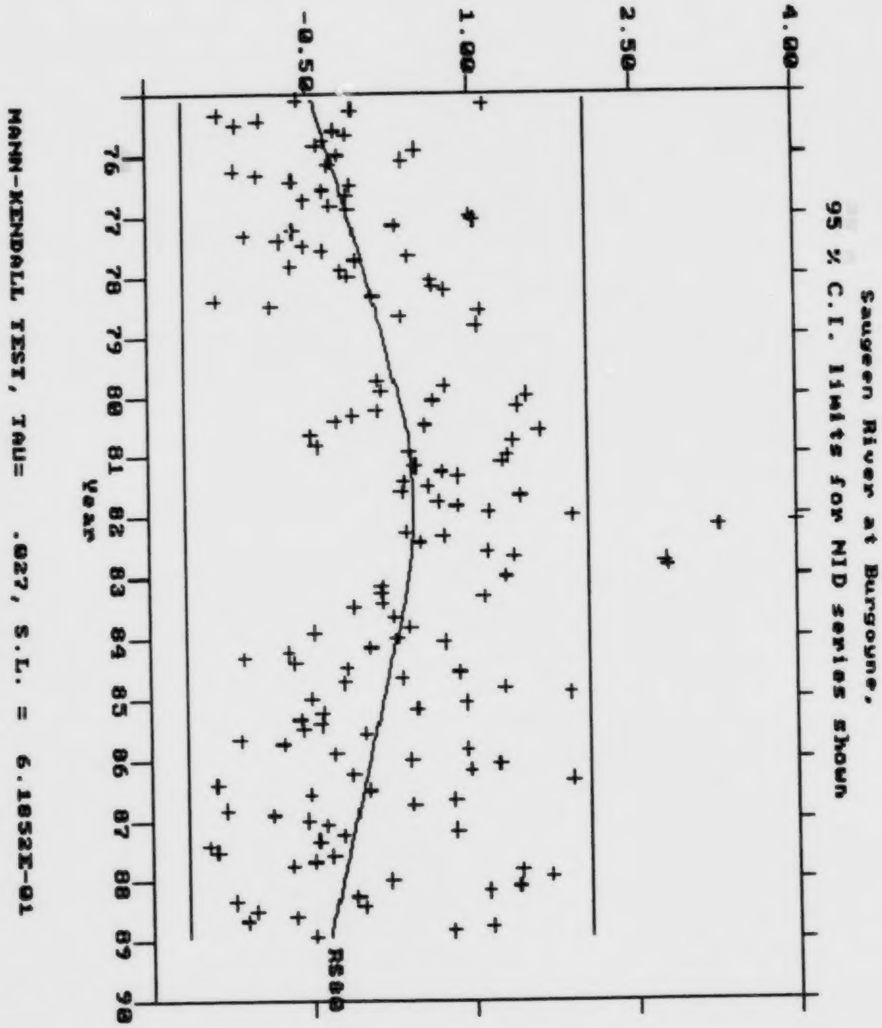
MANN-KENDALL TEST, TAU= -.073, S.L. = 1.7693E-01

Saugeen.FRP.6

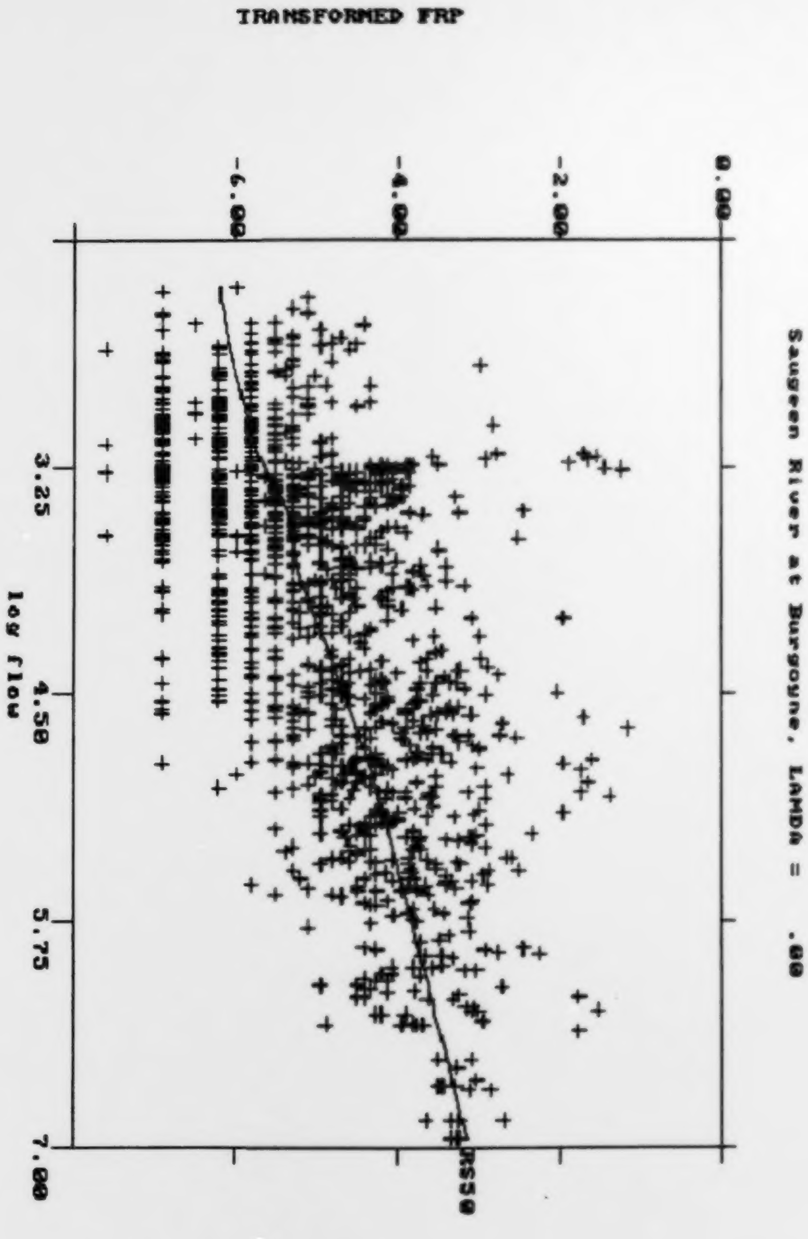


MANN-KENDALL TEST, TAU= -.059, S.L. = 2.8157E-01

Monthly Flow-detrended FRP



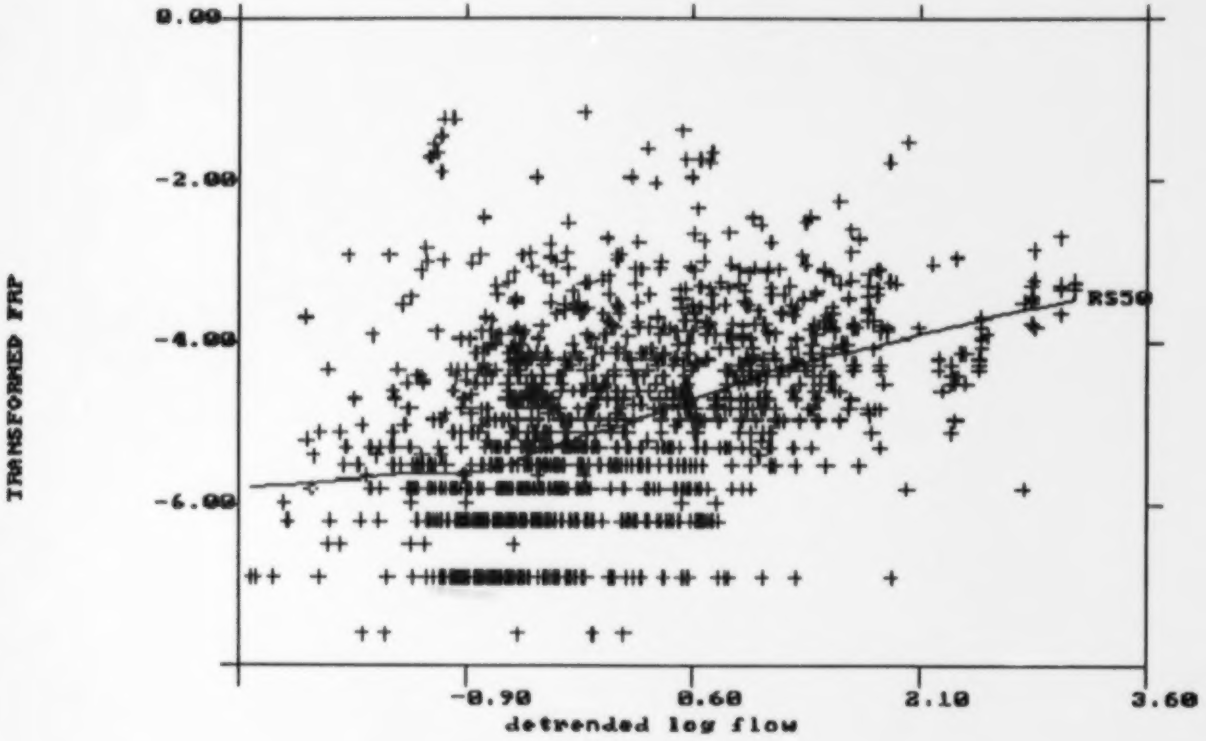
Saugeen.FRP.8



KENDALL RANK CORRELATION, TAU= .434, S.L. = 0.0000E+00

Saugeen.FRP.9

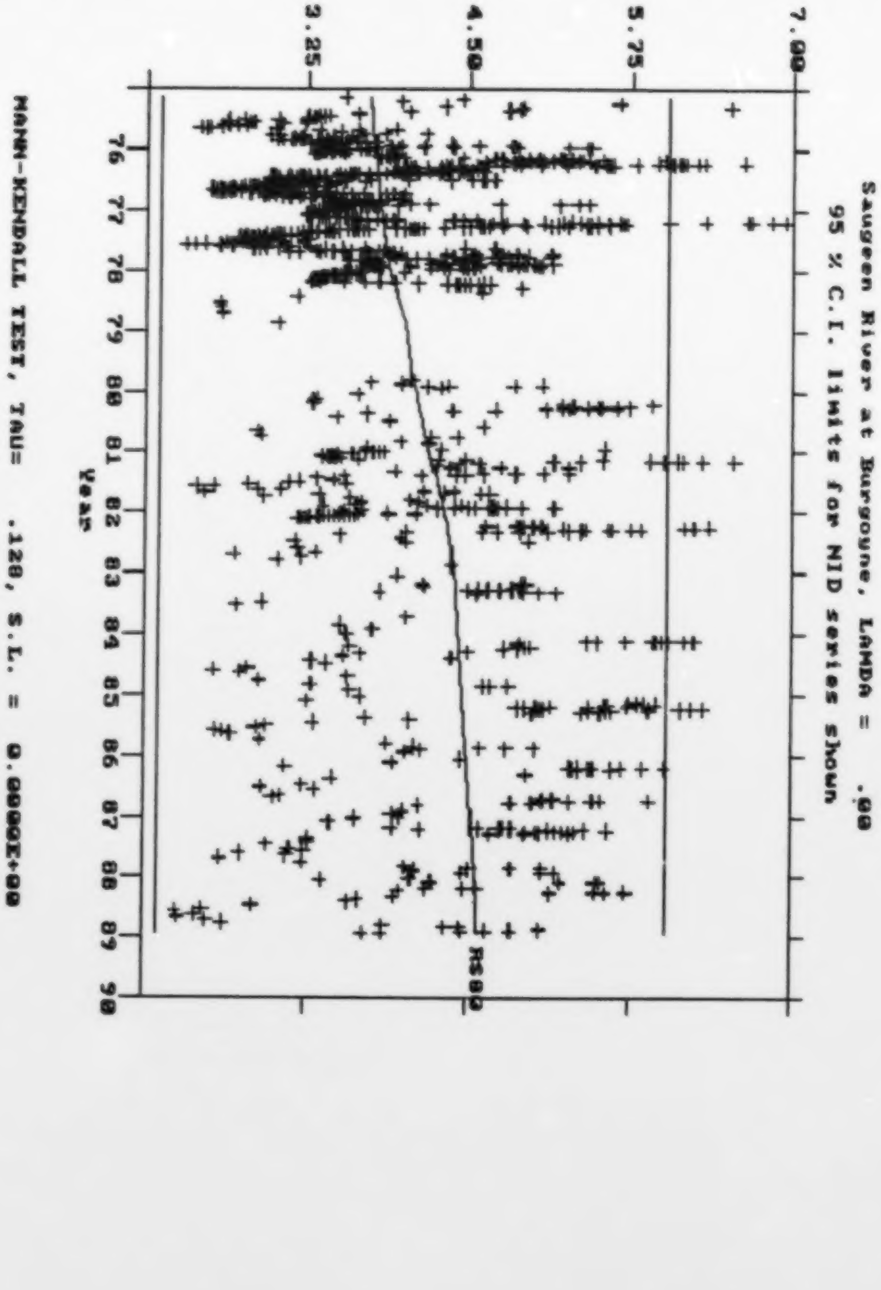
Saugeen River at Burgoyne, LAMDA = .00



KENDALL RANK CORRELATION, TAU= .307, S.L. = 0.0000E+00

Saugeen.FRP.10

TRANSFORMED flow @ FRP



Saugeen.FRP.11

```
    Trend tests for mean monthly data

    Site: Saugeen River at Burgoyne,

    parameter: FRP

    Basic data - not adjusted for flow

    Mann-Kendall Trend Test
          tau          Significance Level
       -.07320              1.76930E-01

    Ordinary Spearman Trend Test
          rho          Significance Level
       -.11970              1.36159E-01

    Seasonal Mann-Kendall Trend Test
    Score          Variance          Significance Level
     -68.             3260.0                 2.33666E-01

    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:   1  2  3  4  5  6  7  8  9 10 11 12
  Rank:   4  5  6  7  5  2  1  2  2  3  4  5

         rho         Significance Level
     -.12034              1.34090E-01
```

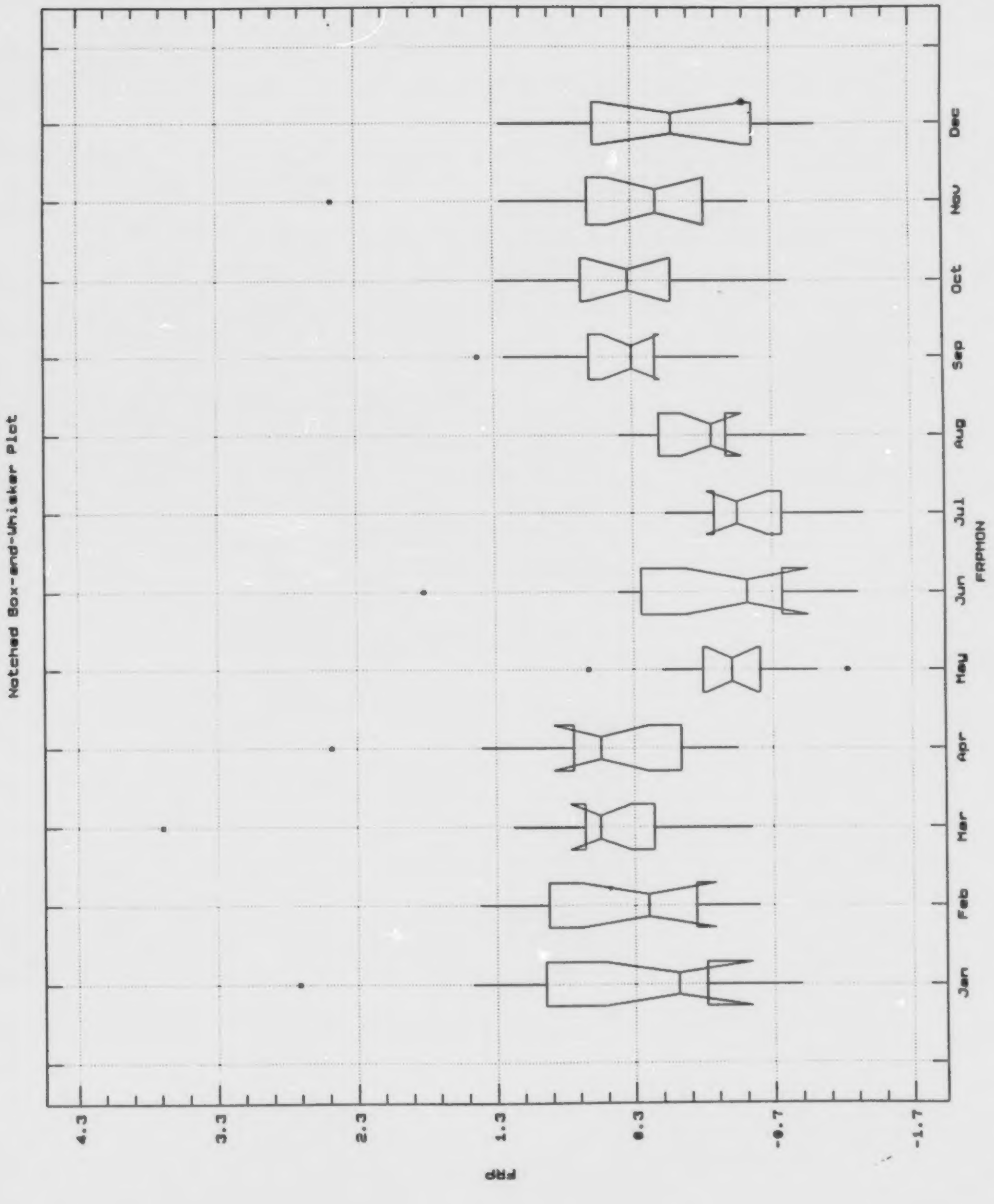
Saugeen.FRP.12

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of FRP by FRPMON
--------------------------------------------------------------------------------
Level          Sample Size    Average Rank
--------------------------------------------------------------------------------
  1               13           83.6923   4
  2               12           91.4167   5
  3               14           112.286   6
  4               14           122.714   7
  5               14           94.1429   5
  6               14           49.4286   2
  7               12           31.8333   1
  8               12           49.2500   2
  9               13           50.0769   2
 10                12           67.0000   3
 11                14           87.0000   4
 12                12           92.9167   5
--------------------------------------------------------------------------------
Test statistic = 55.3428  Significance level  = 6.70683E-8
```

Saugeen.FRP.13

```
     Trend tests for mean monthly data


     Site: Saugeen River at Burgoyne,

     parameter: FRP

     Flow-adjusted Data


     Mann-Kendall Trend Test
           tau           Significance Level
        -.05907                2.81574E-01


     Ordinary Spearman Trend Test
           rho           Significance Level
        -.10162                2.13281E-01


     Seasonal Mann-Kendall Trend Test
     Score           Variance           Significance Level
      -57.             2953.0                  2.94214E-01


     Spearman Trend Test Partialling Out Seasonality

     Seasonal rankings:
 Season:    1  2  3  4  5  6  7  8  9 10 11 12
   Rank:    5  6  7  6  2  2  1  3  7  6  5  4

          rho          Significance Level
      -.10356                2.04665E-01
```

Saugeen.FRP.14



SAUGEEN.FRP.15

```
------------------------------------------------------------------
Kruskal-Wallis analysis of FRP by FRPMON
------------------------------------------------------------------
Level              Sample Size      Average Rank
------------------------------------------------------------------
  1                     12              85.7500 5
  2                     12              92.0000 6
  3                     13              101.846 7
  4                     13              95.9231 6
  5                     13              42.4615 2
  6                     13              47.1538 2
  7                     12              34.6667 1
  8                     12              58.0000 3
  9                     13              98.3846 7
 10                     12              93.9167 6
 11                     14              87.1429 6
 12                     12              72.4167 4
------------------------------------------------------------------
Test statistic = 41.9022  Significance level  = 1.68408E-5
```

Saugeen.FRP.16

```
    Trend tests for mean monthly data

    Site: Saugeen River at Burgoyne,

    parameter: FRP

    Flow-adjusted Data


    Mann-Kendall Trend Test
          tau          Significance Level
        .02746              6.18522E-01

    Ordinary Spearman Trend Test
          rho          Significance Level
        .02938              7.18946E-01

    Seasonal Mann-Kendall Trend Test
    Score              Variance             Significance Level
      17.                2953.0                      7.54405E-01

    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    6  7  9  8  4  3  1  2  5  5  5  6

         rho          Significance Level
       .02894              7.23037E-01
```

Saugeen.FRP.17

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of FRP by FRPMON
--------------------------------------------------------------------------------
Level          Sample Size    Average Rank
--------------------------------------------------------------------------------
 1                 12            85.4167  6
 2                 12            90.2500  7
 3                 13            112.308  9
 4                 13            106.385  8
 5                 13            60.2308  4
 6                 13            54.1538  3
 7                 12            33.2500  1
 8                 12            48.8333  2
 9                 13            76.0000  5
 10                 12            78.6667 5
 11                 14            80.1429 5
 12                 12            83.2500 6
--------------------------------------------------------------------------------
Test statistic = 38.5956  Significance level  = 6.20427E-5
```

Saugeen.TP

Saugeen River at Burgoyne

Total Phosphorus

Table of Contents: Saugeen.TP

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs TP

(9) Scatter and smooth of detrended-flow vs TP

(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box-and-whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Summary and Conclusions

Saugeen River - TP

Data Transformation: logarithmic

Seasonality: very strong in the unadjusted data but not significant at 5% in either the flow-adjusted or detrended-flow-adjusted data.

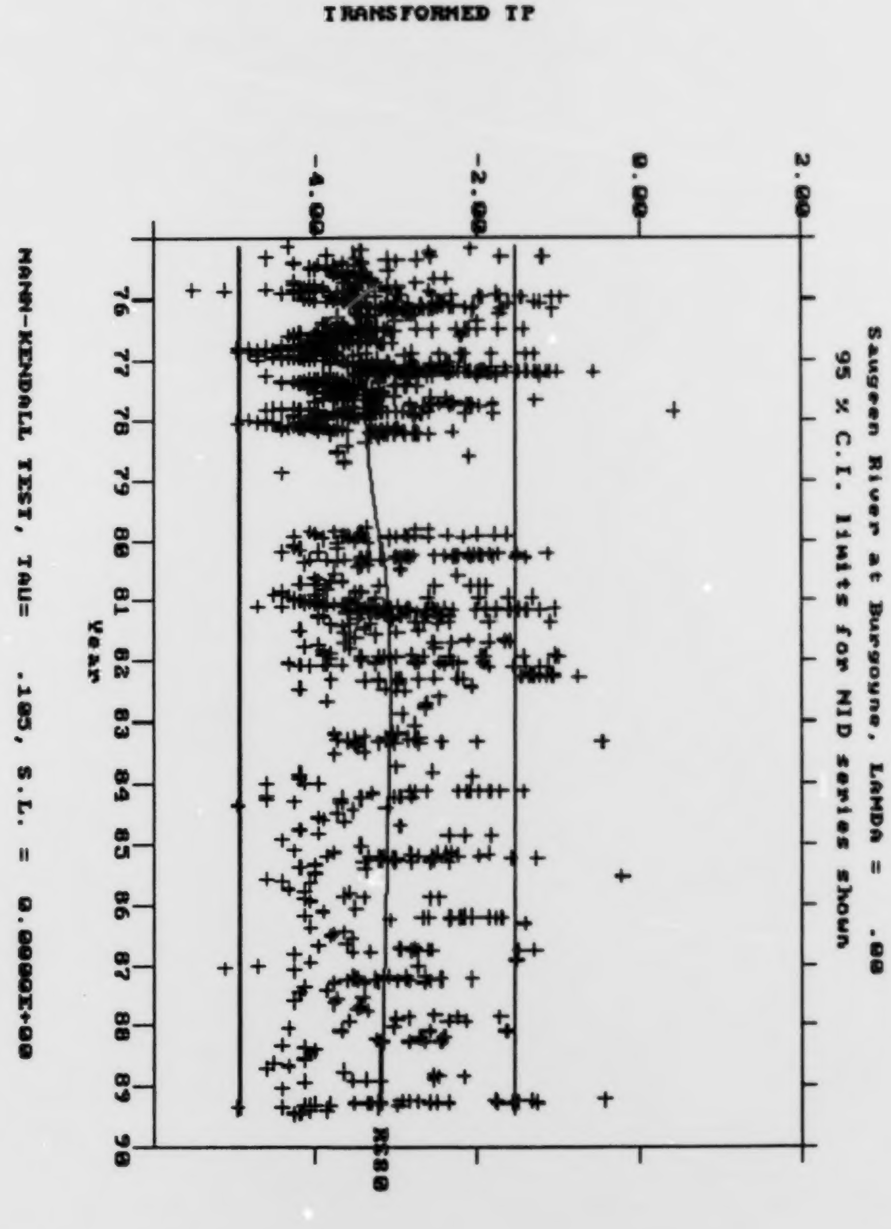
Flow-Concentration Relationship: Constant at low levels but positive increasing at moderate to high flow.

Outliers: none apparent

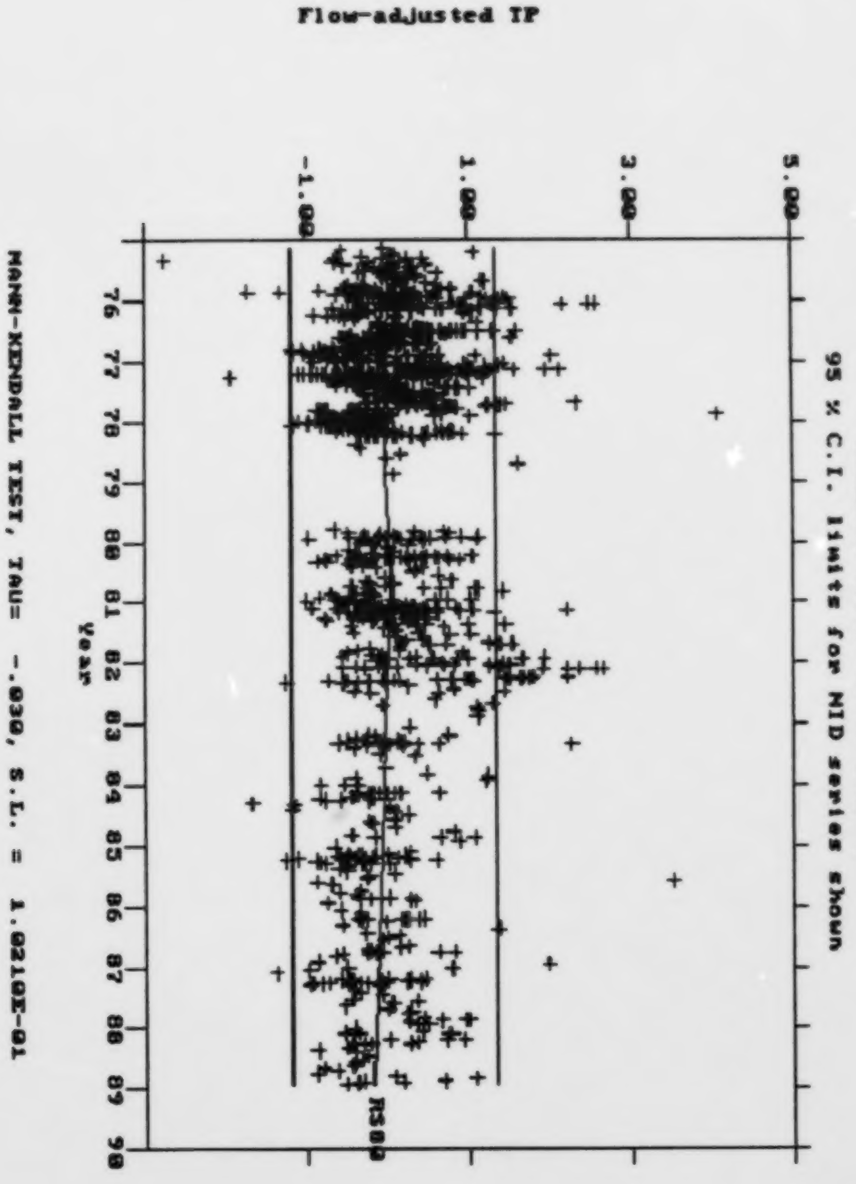
Trend: Some suggestion of a slight decline in mean monthly data but not reflected in the full data set. Trend tests significant for unadjusted data set but not at all for the detrended-flow-adjusted data. Only the MK test is significant at 5% for the flow-adjusted data..

Other:

Saugeen.TP.2


TRANSFORMED TP
2.00
0.00
-2.00
-4.00
Saugeen River at Burgoyne, LAMDA = .00
95 % C.I. limits for NID series shown
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Year
KS80
MANN-KENDALL TEST, TAU= .185, S.L. = 0.0000E+00

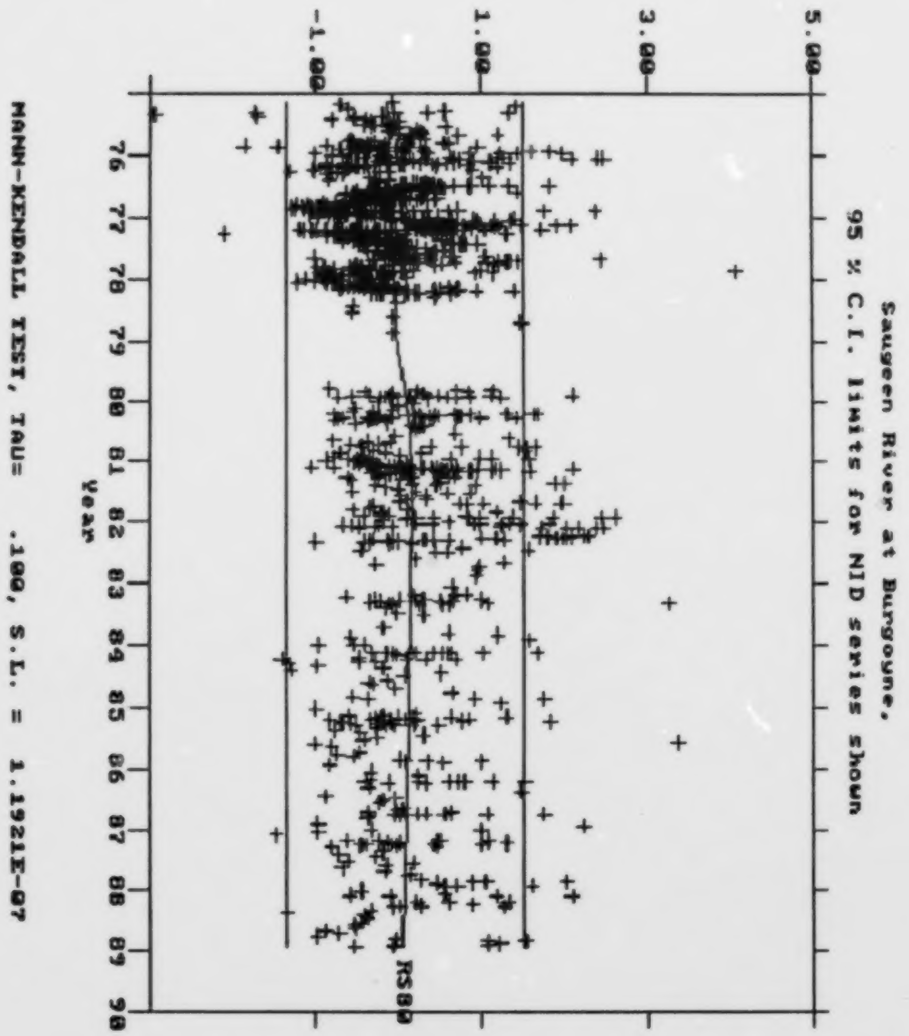
Saugeen.TP.3


Flow-adjusted TP
Saugeen River at Burgoyne,
95 % C.I. limits for MID series shown
-1.00
1.00
3.00
5.00
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Year
R380
MANN-KENDALL TEST, TAU= -.030, S.L. = 1.0210E-01

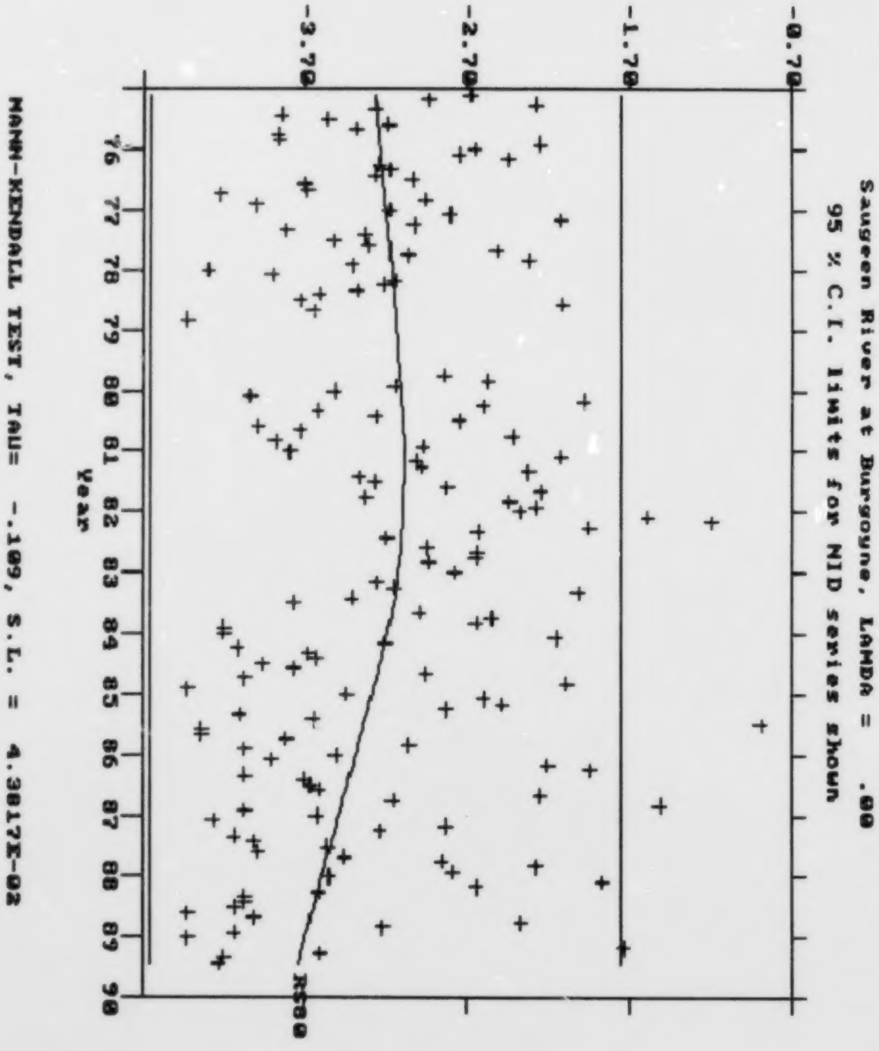
Saugeen.TP.4

Detrended

Flow-adjusted TP



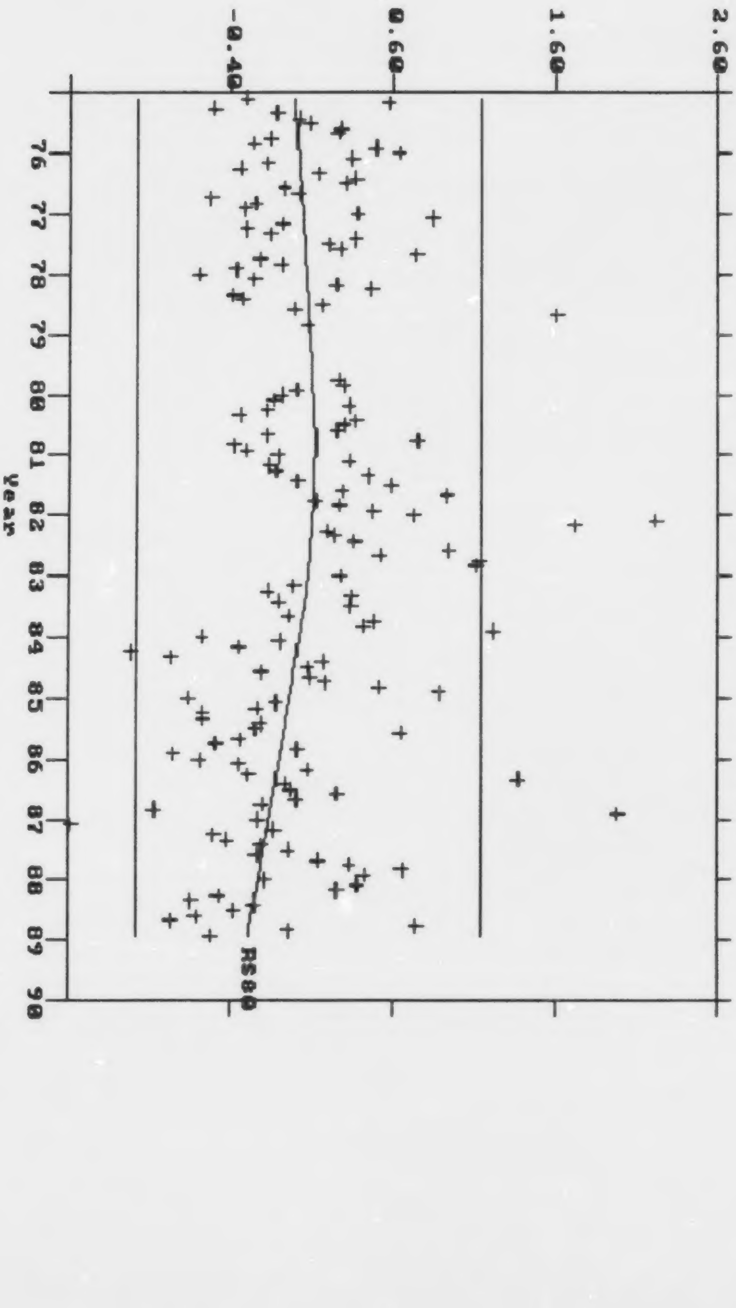
Monthly TP



MANN-KENDALL TEST, TAU= -.109, S.L. = 4.3817E-02

Saugeen.TP.6

Monthly Flow adjusted TP

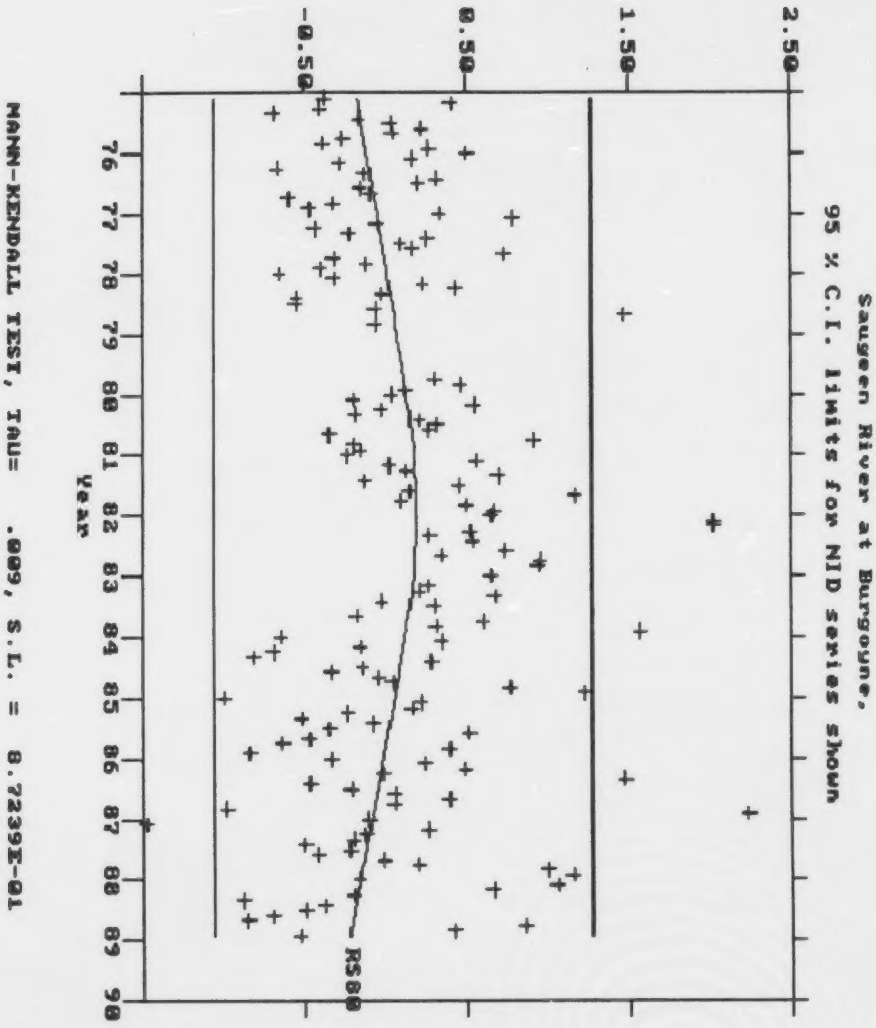


Saugeen River at Burgoyne,
95 % C.I. limits for NID series shown

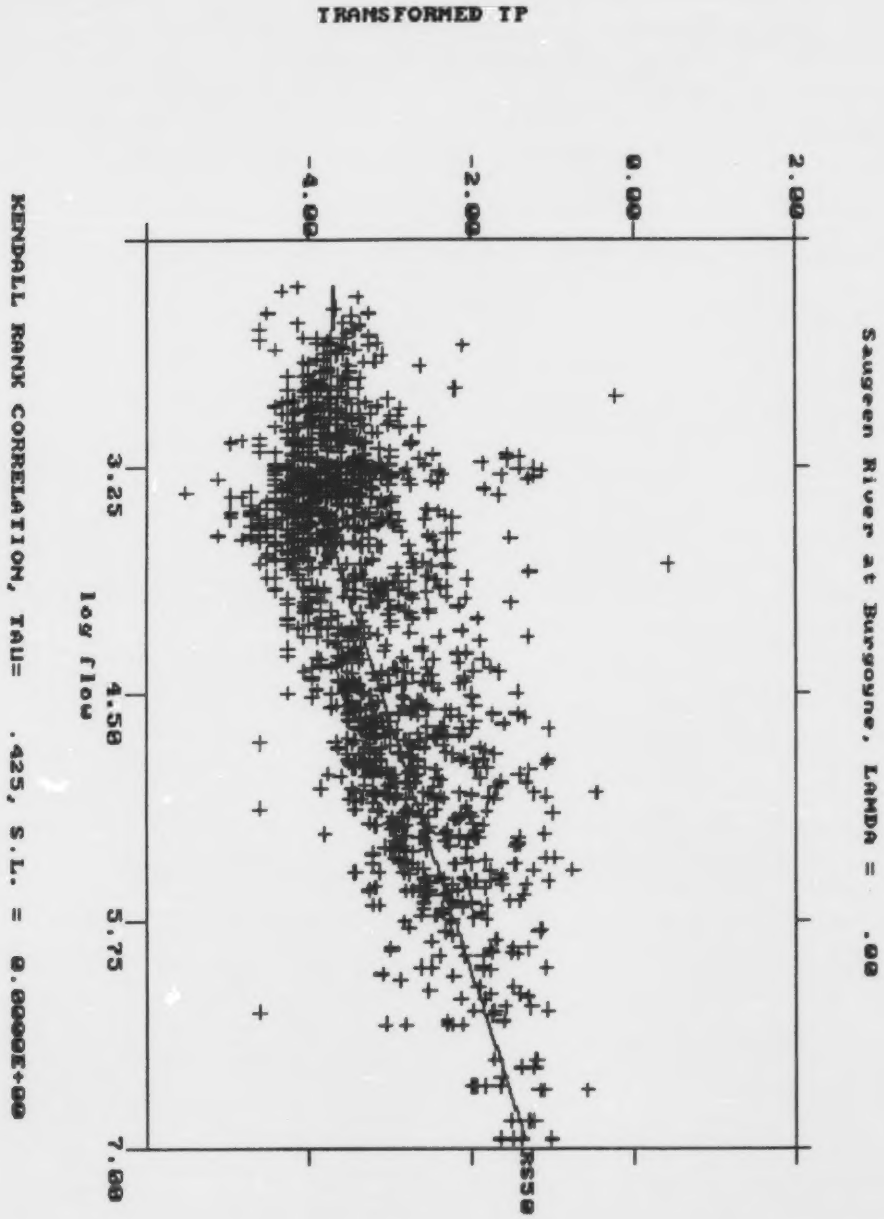
MANN-KENDALL TEST, TAU= -.109, S.L. = 4.5787E-02

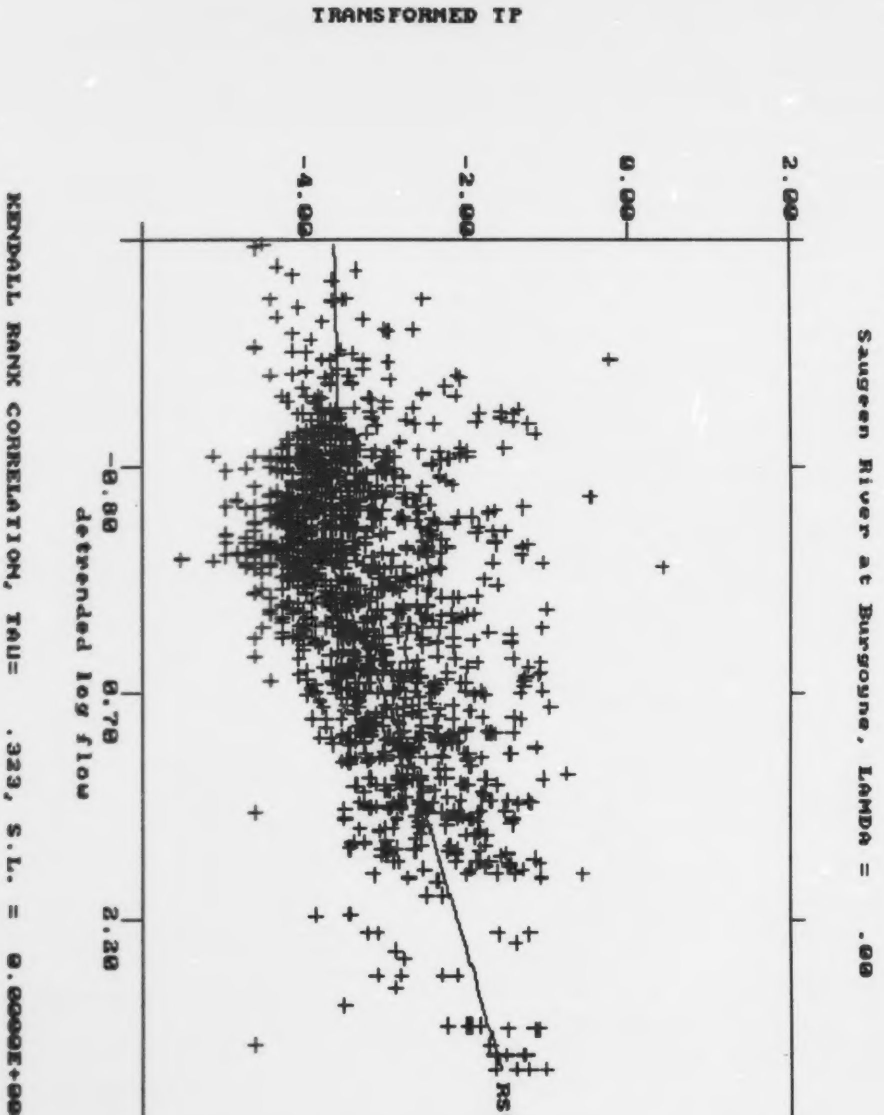
Saugeen.TP.7

Monthly Flow-detrended TP



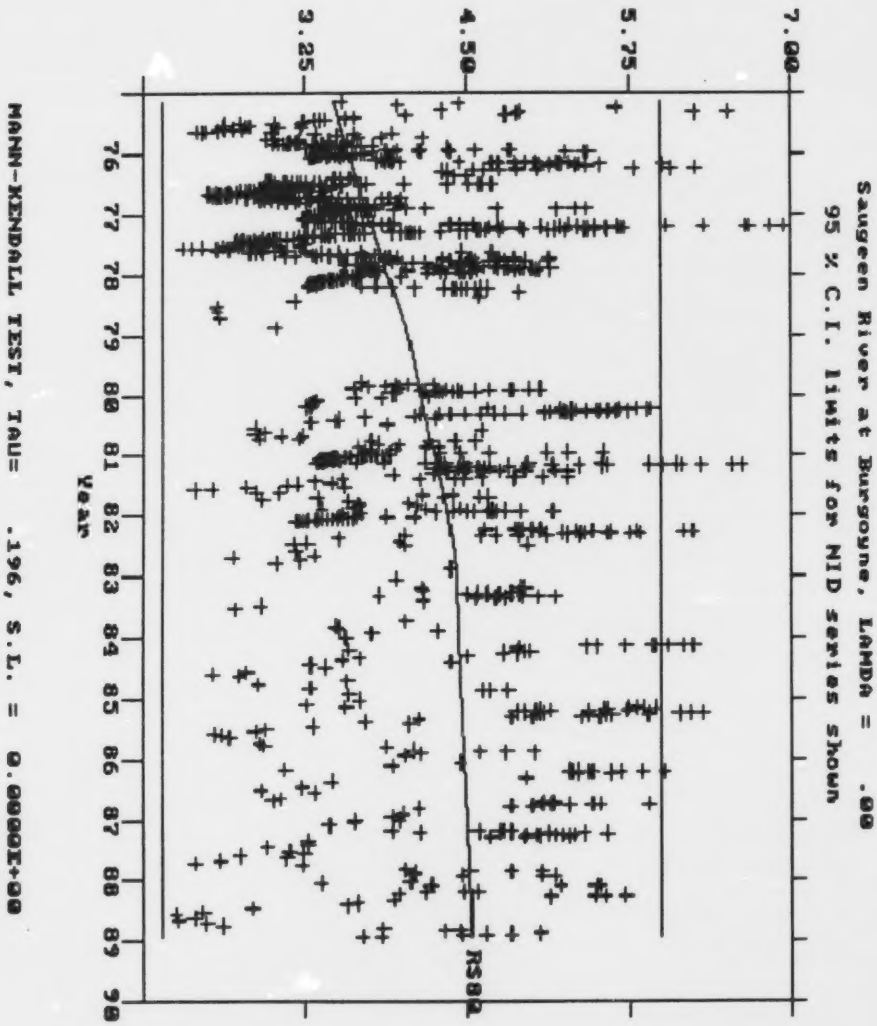
Saugeen.TP.8


TRANSFORMED TP
-4.00
-2.00
0.00
2.00
Saugeen River at Burgoyne, LAMDA = .00
3.25
4.50
5.75
7.00
log flow
RS50
KENDALL RANK CORRELATION, TAU= .425, S.L. = 0.0000E+00


TRANSFORMED TP
Saugeen River at Burgoyne, LAMDA = .00
-4.00
-2.00
0.00
2.00
-0.80
0.70
2.20
3.70
detrended log flow
RS50
KENDALL RANK CORRELATION, TAU= .323, S.L. = 0.0000E+00

Saugeen.TP.10

TRANSFORMED flow @ TP



Saugeen.TP.11

```
    Trend tests for mean monthly data


    Site: Saugeen River at Burgoyne,

    parameter: TP

    Basic data - not adjusted for flow


    Mann-Kendall Trend Test
          tau          Significance Level
       -.10871              4.38166E-02


    Ordinary Spearman Trend Test
          rho          Significance Level
       -.16953              3.42245E-02


    Seasonal Mann-Kendall Trend Test
    Score          Variance          Significance Level
    -153.             3321.0                    7.93192E-03


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:   1  2  3  4  5  6  7  8  9 10 11 12
  Rank:   2  2  5  8  6  2  1  3  1  4  4  7

         rho          Significance Level
     -.17051              3.32020E-02
```

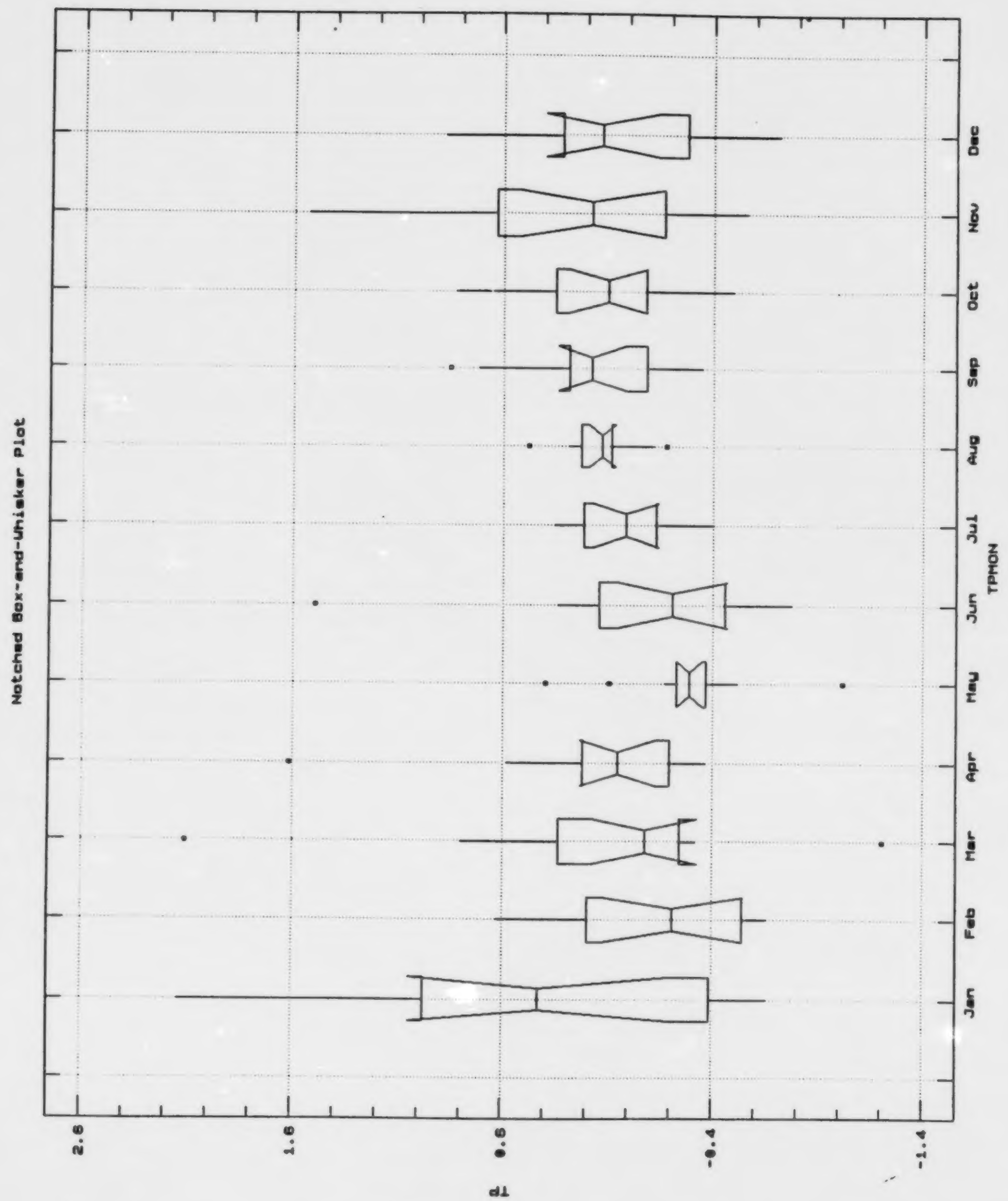
Saugeen.TP.12

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of TP by TPMON
--------------------------------------------------------------------------------
Level          Sample Size     Average Rank
--------------------------------------------------------------------------------
  1               13             64.9231  2
  2               12             61.6667  2
  3               14             89.7857  5
  4               14             121.071  8
  5               14             97.6429  6
  6               14             62.3571  2
  7               12             53.8333  1
  8               12             69.5000  3
  9               13             56.6923  1
 10                13             76.9231  4
 11                14             79.3571  4
 12                12             108.250  7
--------------------------------------------------------------------------------
Test statistic  =  32.32  Significance level  =  6.77546E-4
```

Saugeen.TP.13

```
Trend tests for mean monthly data


Site: Saugeen River at Burgoyne,

parameter: TP

Flow-adjusted Data


Mann-Kendall Trend Test
      tau            Significance Level
   -.10910                4.57875E-02


Ordinary Spearman Trend Test
      rho            Significance Level
   -.17481                3.17092E-02


Seasonal Mann-Kendall Trend Test
Score             Variance             Significance Level
-121.               3009.0                     2.73951E-02


Spearman Trend Test Partialling Out Seasonality

Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    6  2  3  4  1  2  3  5  6  4  6  3

     rho           Significance Level
  -.17373               3.27783E-02
```

Saugeen.TP.14



SAUGEEN.TP.15

```
-----------------------------------------------------------
Kruskal-Wallis analysis of TP by TPMON
-----------------------------------------------------------
Level            Sample Size     Average Rank
-----------------------------------------------------------
  1                  12               91.7500 6
  2                  12               58.2500 2
  3                  13               77.0769 3
  4                  13               82.0769 4
  5                  13               39.7692 1
  6                  13               59.0000 2
  7                  12               77.1667 3
  8                  12               89.0000 5
  9                  13               91.0000 6
 10                  13               84.2308 4
 11                  14               91.8571 6
 12                  12               76.4167 3
-----------------------------------------------------------
Test statistic = 19.3028  Significance level  = 0.0558708
```

Saugeen.TP.16

```
    Trend tests for mean monthly data

    Site: Saugeen River at Burgoyne,

    parameter: TP

    Flow-adjusted Data


    Mann-Kendall Trend Test
          tau            Significance Level
       .00889                 8.72392E-01


    Ordinary Spearman Trend Test
          rho            Significance Level
      -.00204                 9.79967E-01


    Seasonal Mann-Kendall Trend Test
    Score            Variance           Significance Level
       7.               3009.0                      8.98457E-01


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    5  1  5  6  1  1  1  2  3  2  4  4

         rho           Significance Level
     -.00163                9.83986E-01
```

SAUGEEN.TP.17

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of TP by TPMON
--------------------------------------------------------------------------------
Level          Sample Size     Average Rank
--------------------------------------------------------------------------------
  1               12           94.2500 5
  2               12           58.0000  1
  3               13           91.0000 5
  4               13           97.8462 6
  5               13           60.0769 1
  6               13           61.9231 1
  7               12           61.4167 1
  8               12           69.3333 2
  9               13           76.7692 3
 10                13           72.5385 2
 11                14           88.1429 4
 12                12           84.6667 4
--------------------------------------------------------------------------------
Test statistic = 14.9962  Significance level  = 0.182669
```

Saugeen.SS

Saugeen River at Burgoyne

Suspended Solids

Table of Contents: Saugeen.SS

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs SS

(9) Scatter and smooth of detrended-flow vs SS

(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box-and-whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Summary and Conclusions

Saugeen River - SS

Data Transformation: logarithmic

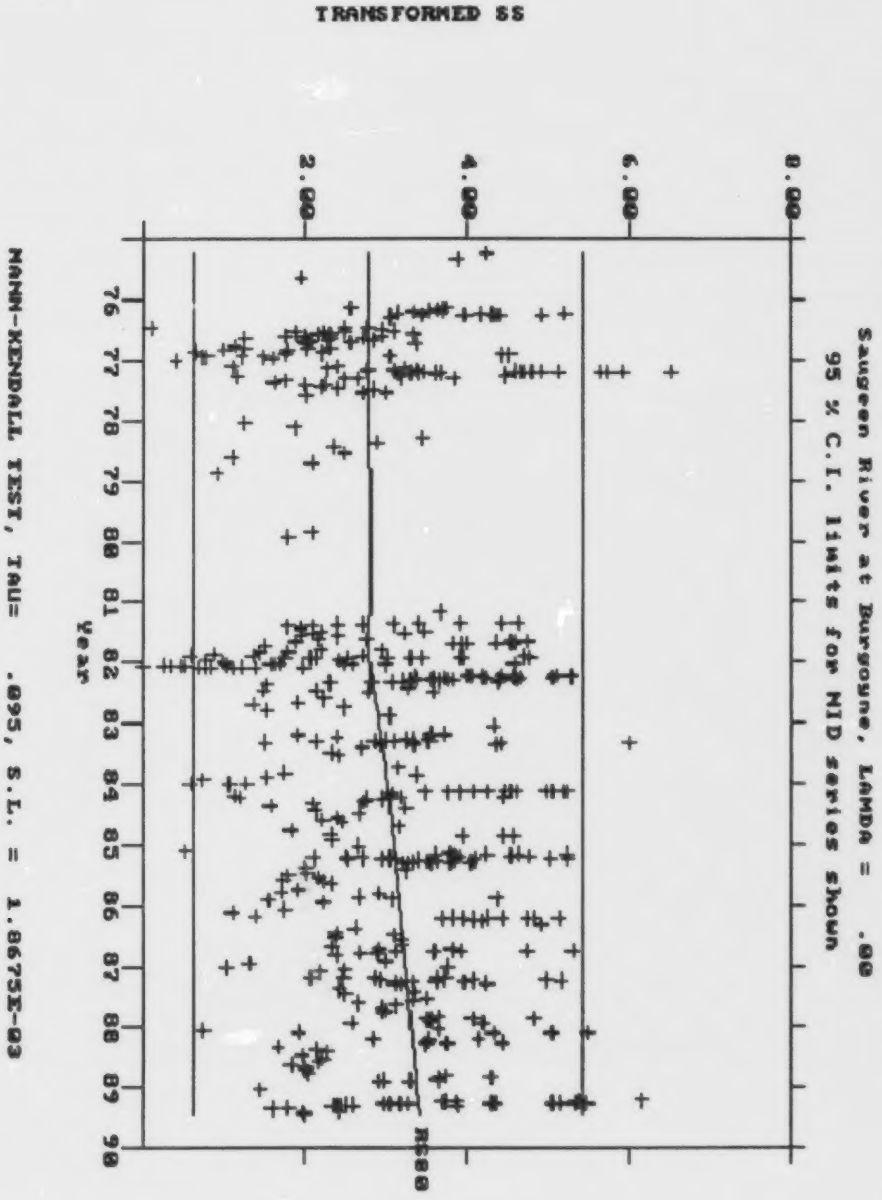
Seasonality: very strong in the unadjusted data. Barely significant in flow-adjusted data and not at all in the detrended-flow-adjusted data. Perhaps due to the better fit provided by the detrended-flow-adjustment method.

Flow-Concentration Relationship: Slightly U-shaped at low flows but otherwise positive increasing relationship.

Outliers: none apparent

Trend: Increasing trend over the period 1982-1989. Significant at 5% on Mann-Kendall Test and Seasonal Spearman Test in the detrended-flow-adjusted data. Since seasonality is weak in both types of flow-adjusted data, the Hirsch-Slack test is not as powerful as the Mann-Kendall test.

Other:



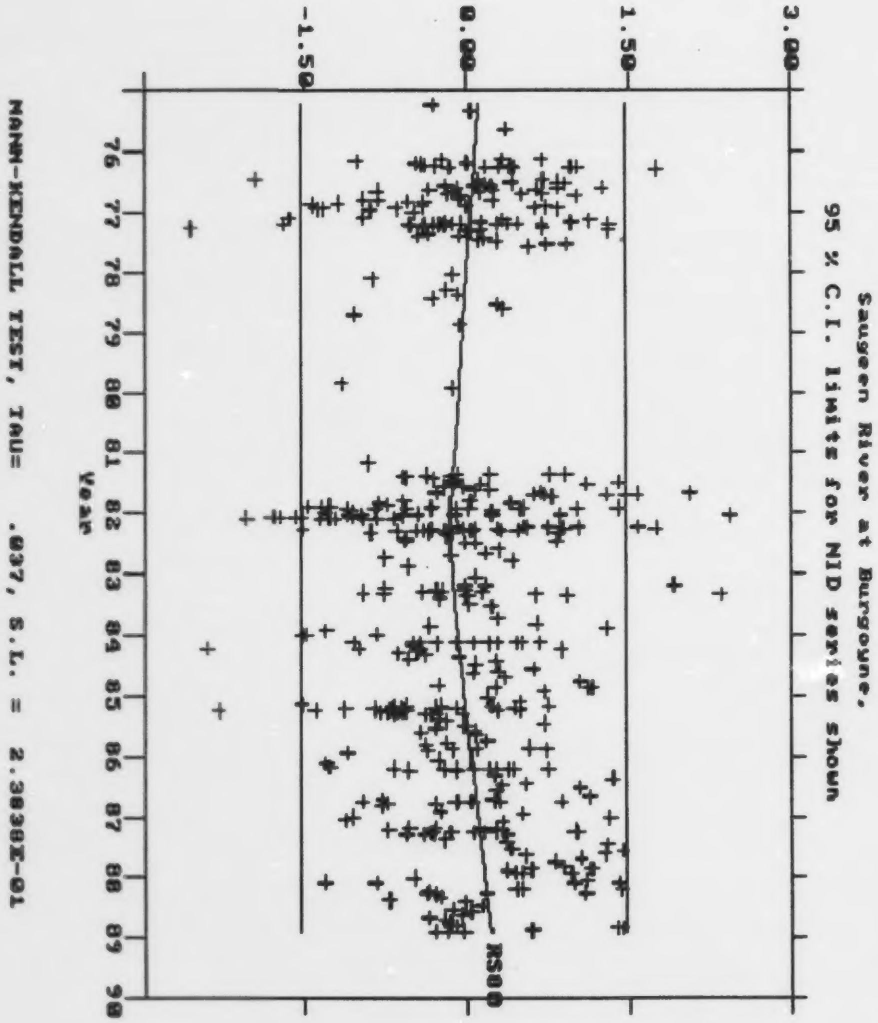
Saugeen River at Burgoyne, LAMDA = .00

95 % C.I. limits for MID series shown

MANN-KENDALL TEST, TAU= .095, S.L. = 1.8675E-03

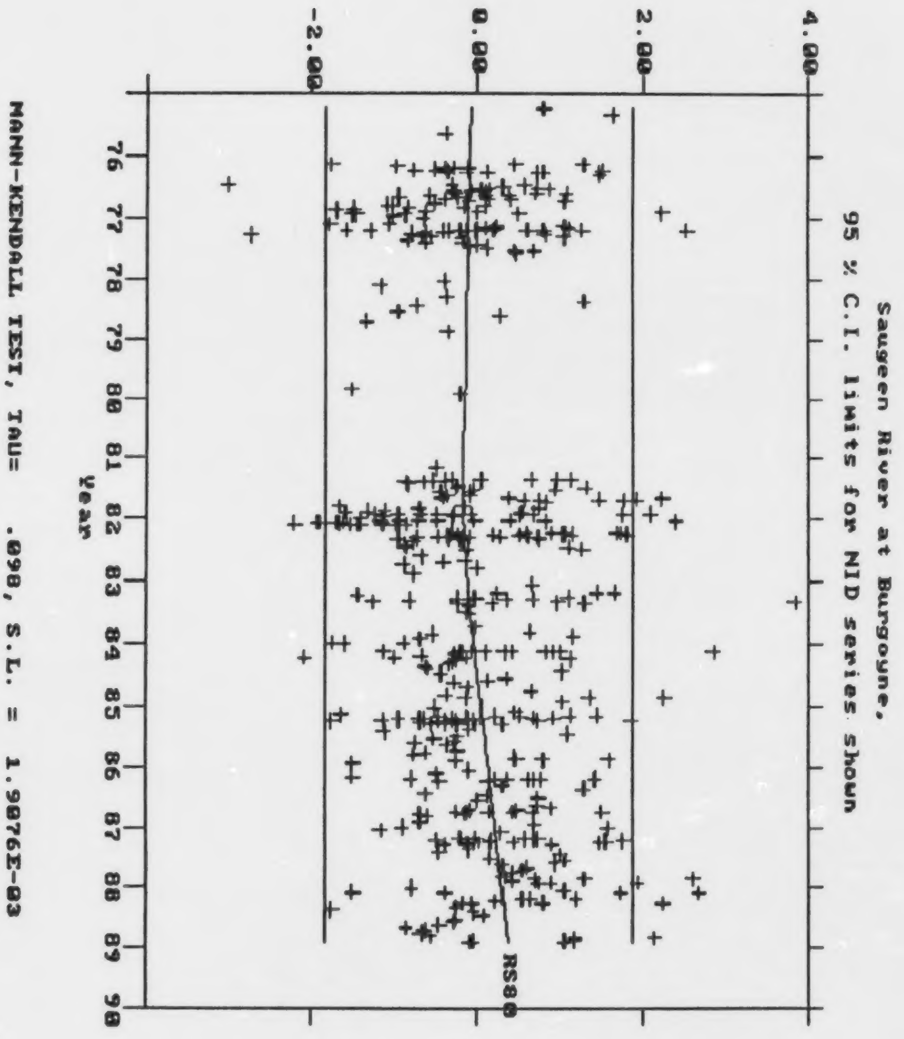
Saugeen.SS.3

Flow-adjusted SS



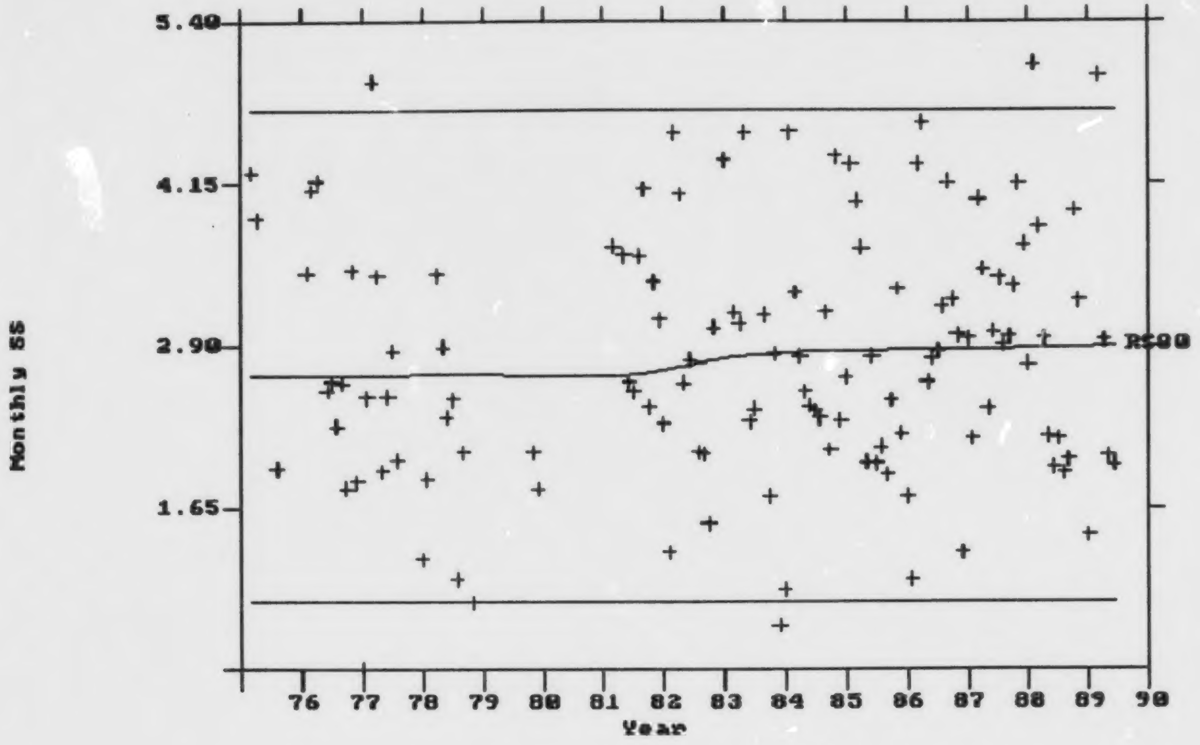
Detrended

Flow-adjusted SS



Saugeen.SS.5

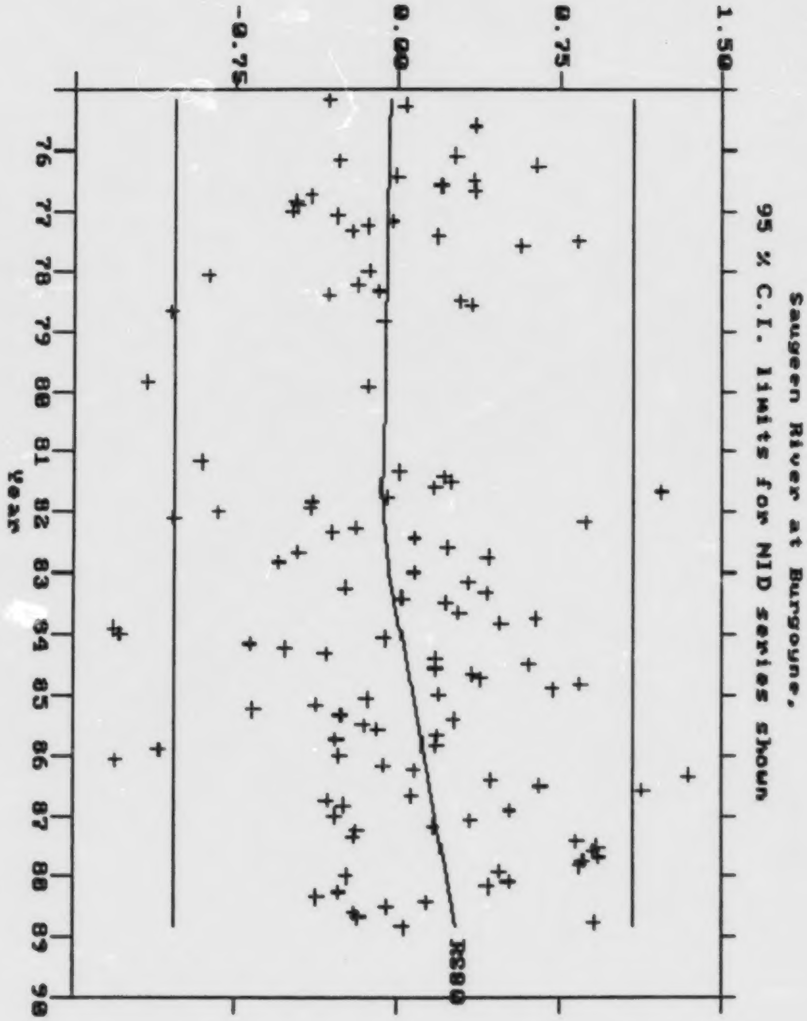
Saugeen River at Burgoyne, LAMDA = .00
95 % C.I. limits for NID series shown



MANN-KENDALL TEST, TAU= .044, S.L. = 4.6679E-01

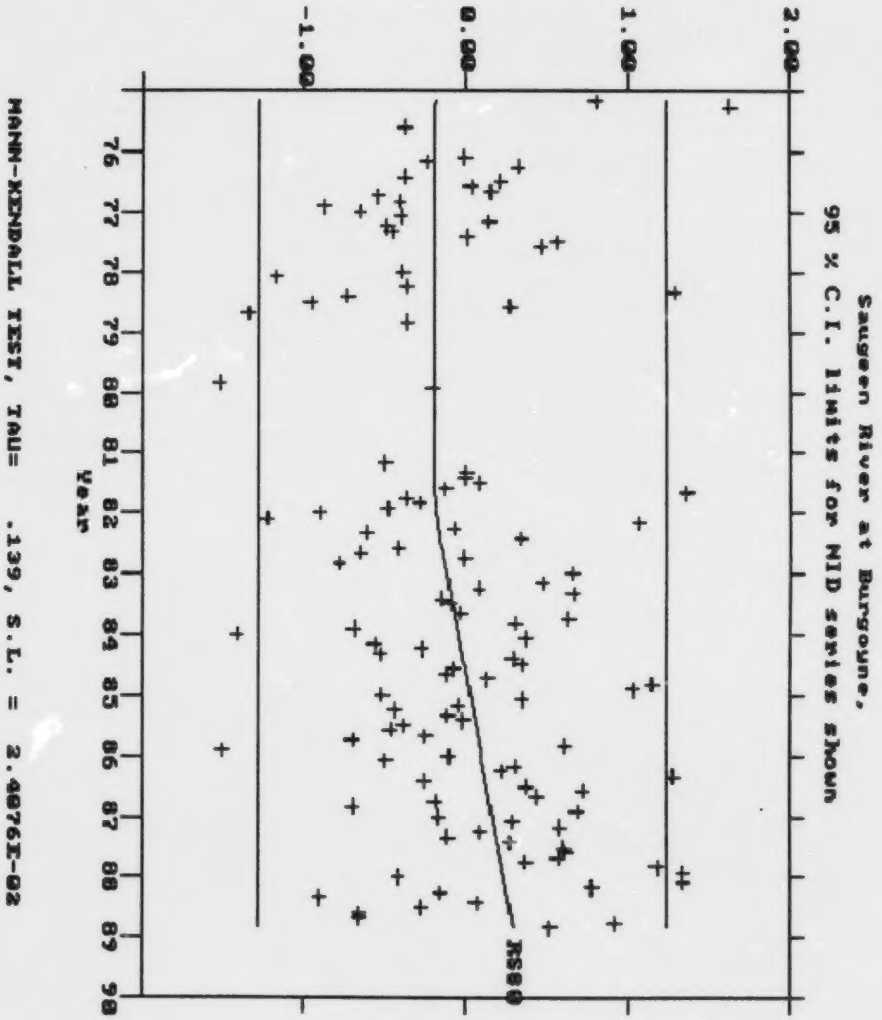
Saugeen.SS.6

Monthly Flow adjusted SS

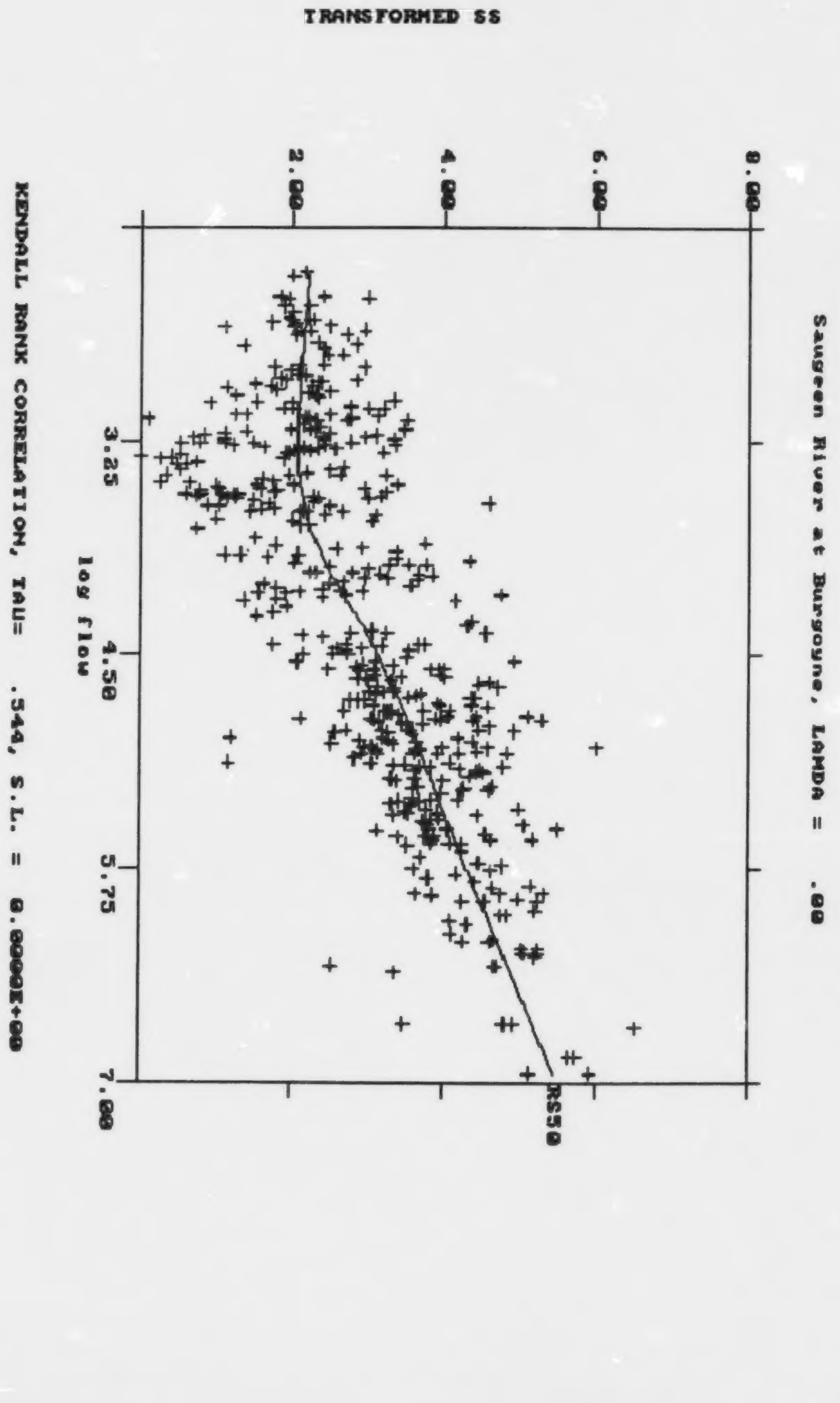


MANN-KENDALL TEST, TAU= .122, S.L. = 4.8842E-02

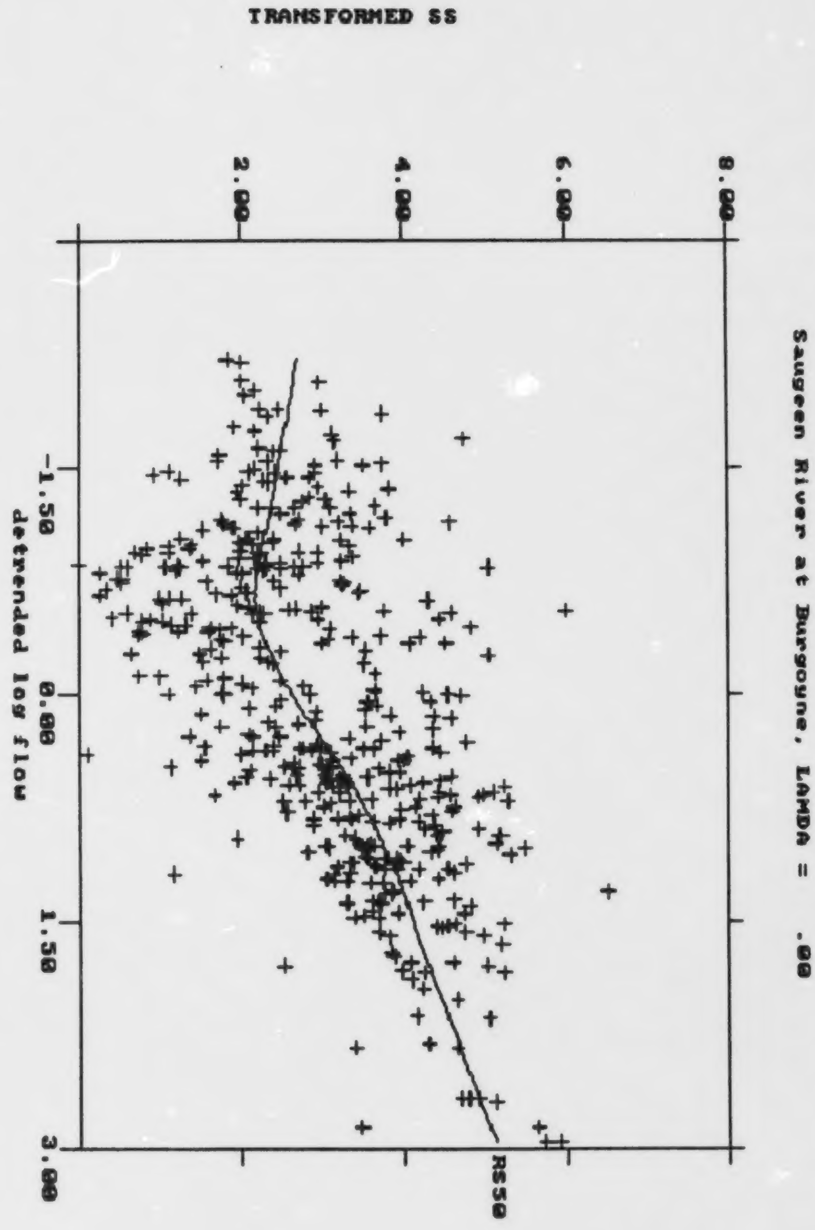
Monthly Flow-detrended SS



Saugeen.SS.8

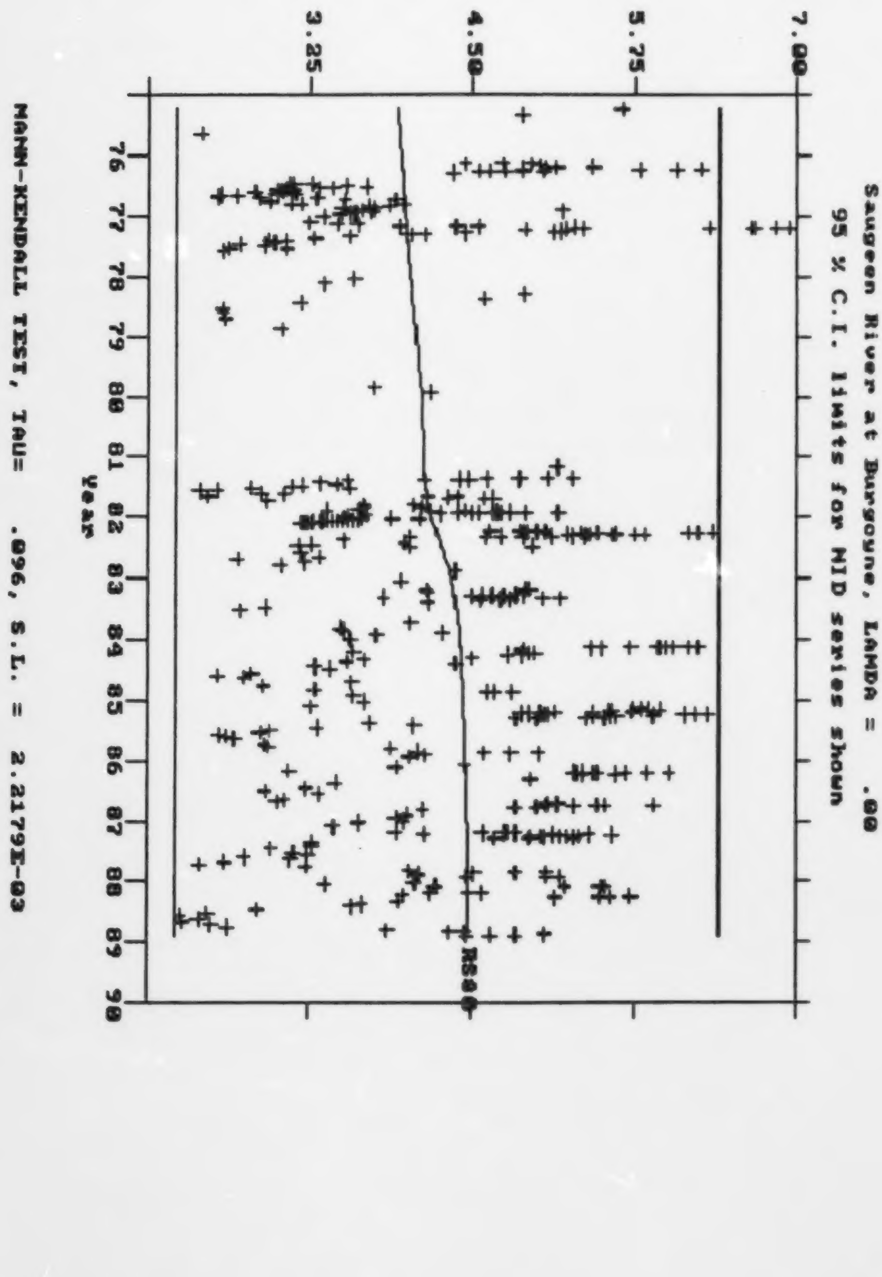

TRANSFORMED SS
Saugeen River at Burgoyne, LAMDA = .00
2.00
4.00
6.00
8.00
3.25
4.50
5.75
7.00
log flow
RS50
KENDALL RANK CORRELATION, TAU= .544, S.L. = 0.0000E+00

Saugeen.SS.9



KENDALL RANK CORRELATION, TAU= .402, S.L. = 0.0000E+00

TRANSFORMED flow @ SS



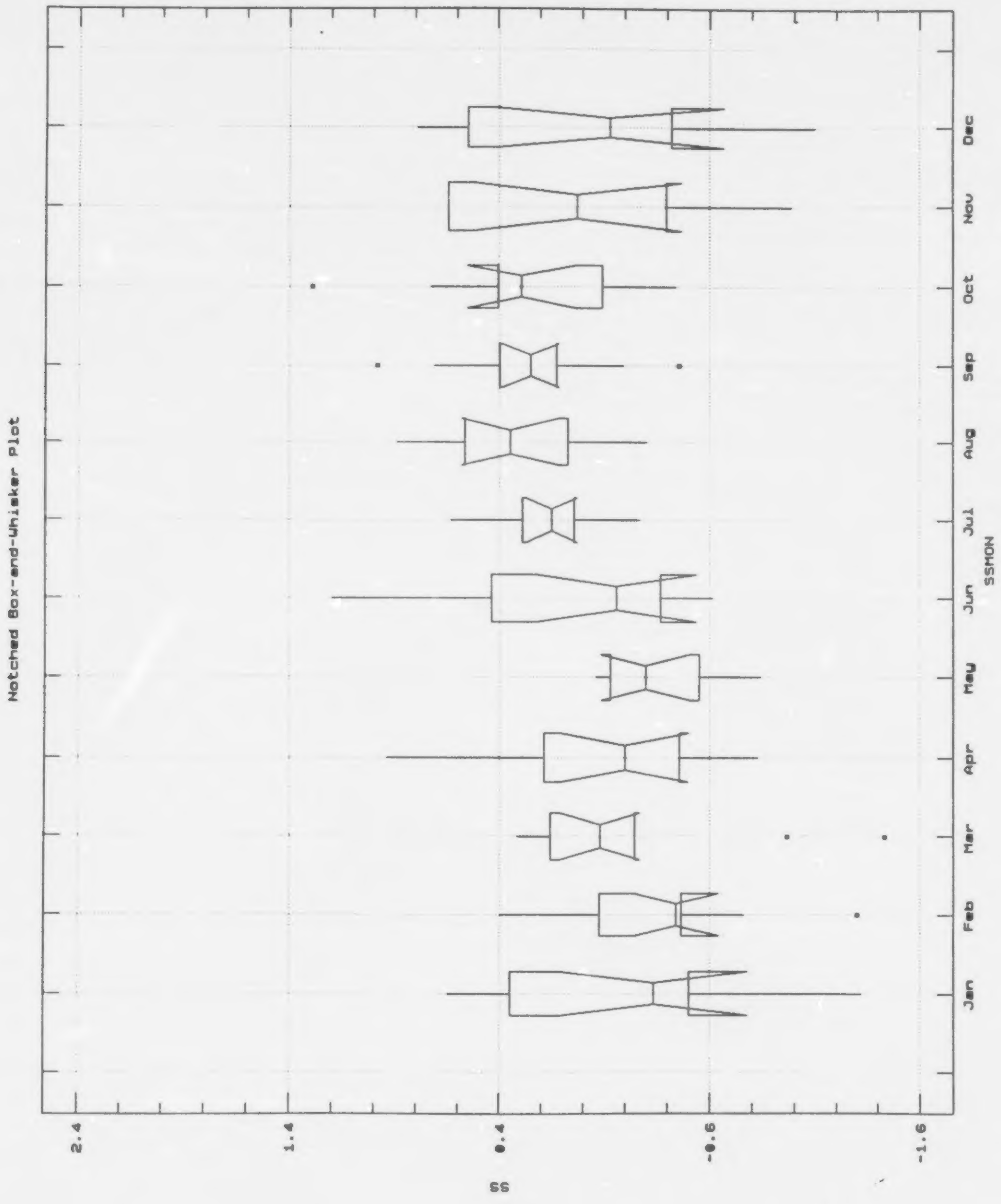
```
Trend tests for mean monthly data

Site: Saugeen River at Burgoyne,

parameter: SS

Basic data - not adjusted for flow

Mann-Kendall Trend Test
      tau          Significance Level
    .04415              4.66786E-01

Ordinary Spearman Trend Test
      rho          Significance Level
    .07106              4.28789E-01

Seasonal Mann-Kendall Trend Test
Score            Variance            Significance Level
  18.               1757.3                    6.67644E-01

Spearman Trend Test Partialling Out Seasonality

Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    2  1  4  8  7  4  3  4  2  5  2  6

    rho          Significance Level
  .06818              4.47732E-01
```

Saugeen.SS.12

```
--------------------------------------------------------------------
Kruskal-Wallis analysis of SS by SSMON
--------------------------------------------------------------------
Level          Sample Size    Average Rank
--------------------------------------------------------------------
  1              10          49.2000  2
  2               9         31.5556  1
  3              12          59.5833  4
  4              12          101.917  8
  5              11          91.0000  7
  6              12          60.2500  4
  7              10          53.1000  3
  8              11          62.0909  4
  9              10          46.3000  2
 10               9          65.0000  5
 11              11           44.5455 2
 12               8          85.6250  6
--------------------------------------------------------------------
Test statistic = 37.7048  Significance level  = 8.77349E-5
```

```
Trend tests for mean monthly data


Site: Saugeen River at Burgoyne,

parameter: SS

Flow-adjusted Data


Mann-Kendall Trend Test
      tau           Significance Level
    .12213               4.80423E-02


Ordinary Spearman Trend Test
      rho           Significance Level
    .18512               4.34390E-02


Seasonal Mann-Kendall Trend Test
Score              Variance            Significance Level
  40.                 1541.3                     3.08273E-01


Spearman Trend Test Partialling Out Seasonality

Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    2  1  2  2  1  3  5  7  6  5  4  3

     rho          Significance Level
   .16454              7.26680E-02
```

Saugeen.SS.14



```
------------------------------------------------------------
Kruskal-Wallis analysis of SS by SSMON
------------------------------------------------------------
Level            Sample Size     Average Rank
------------------------------------------------------------
  1                    9             52.4444 2
  2                    9             36.3333 1
  3                   11             51.3636 2
  4                   11             52.8182 2
  5                   10             33.8000 1
  6                   11             59.5455 3
  7                   10             72.3000 5
  8                   11             84.6364 7
  9                   10             79.1000 6
 10                    9             75.2222 5
 11                   11             65.7273 4
 12                    8             59.6250 3
------------------------------------------------------------
Test statistic = 23.1935  Significance level  = 0.0165968
```

```
    Trend tests for mean monthly data

    Site: Saugeen River at Burgoyne,

    parameter: SS

    Flow-adjusted Data

    Mann-Kendall Trend Test
          tau            Significance Level
        .13922                2.40760E-02

    Ordinary Spearman Trend Test
          rho            Significance Level
        .20385                2.61678E-02

    Seasonal Mann-Kendall Trend Test
    Score           Variance           Significance Level
      72.             1541.3                   6.66635E-02

    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    3  1  5  6  2  4  3  6  4  4  3  4

         rho           Significance Level
       .20643                2.43288E-02
```

SAUGEEN.SS.17

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of SS by SSMON
--------------------------------------------------------------------------------
Level        Sample Size    Average Rank
--------------------------------------------------------------------------------
  1              9            57.3333  3
  2              9            27.5556  1
  3             11            68.8182  5
  4             11            75.7273  6
  5             10            48.8000  2
  6             11            64.1818  4
  7             10            57.0000  3
  8             11            74.5455  6
  9             10            62.7000  4
 10              9            62.6667  4
 11             11            55.0909  3
 12              8            65.6250  4
--------------------------------------------------------------------------------
Test statistic = 14.548  Significance level  = 0.204137
```

Saugeen.ALK

Saugeen River at Burgoyne

Alkalinity

Table of Contents: Saugeen.ALK

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs ALK

(9) Scatter and smooth of detrended-flow vs ALK

(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box-and-whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Summary and Conclusions

Saugeen River - ALK

Data Transformation: none

Seasonality: Very strong in unadjusted data but less strong in flow-adjusted and detrended-flow adjusted data.

Flow-Concentration Relationship: inverted U-shape.

Outliers: none apparent

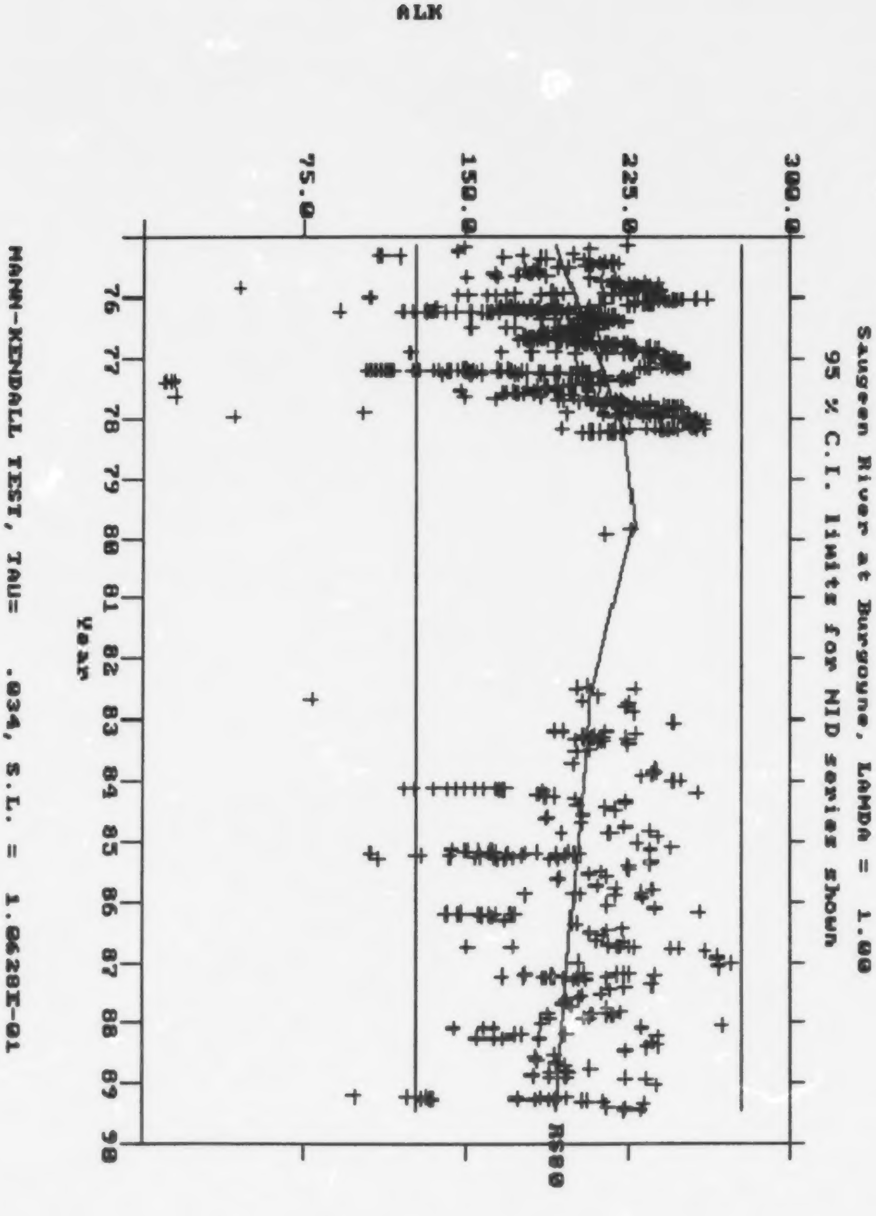
Trend: All tests are highly significant in the flow-adjusted data but not in the unadjusted or detrended-flow-adjusted data (only the Seasonal Spearman is significant at 5% in the detrended-flow-adjusted data) Probably the detrended-flow adjustment procedure removes a substantial bias in this case.

Other: Note that the data are comprised of basically two chunks:

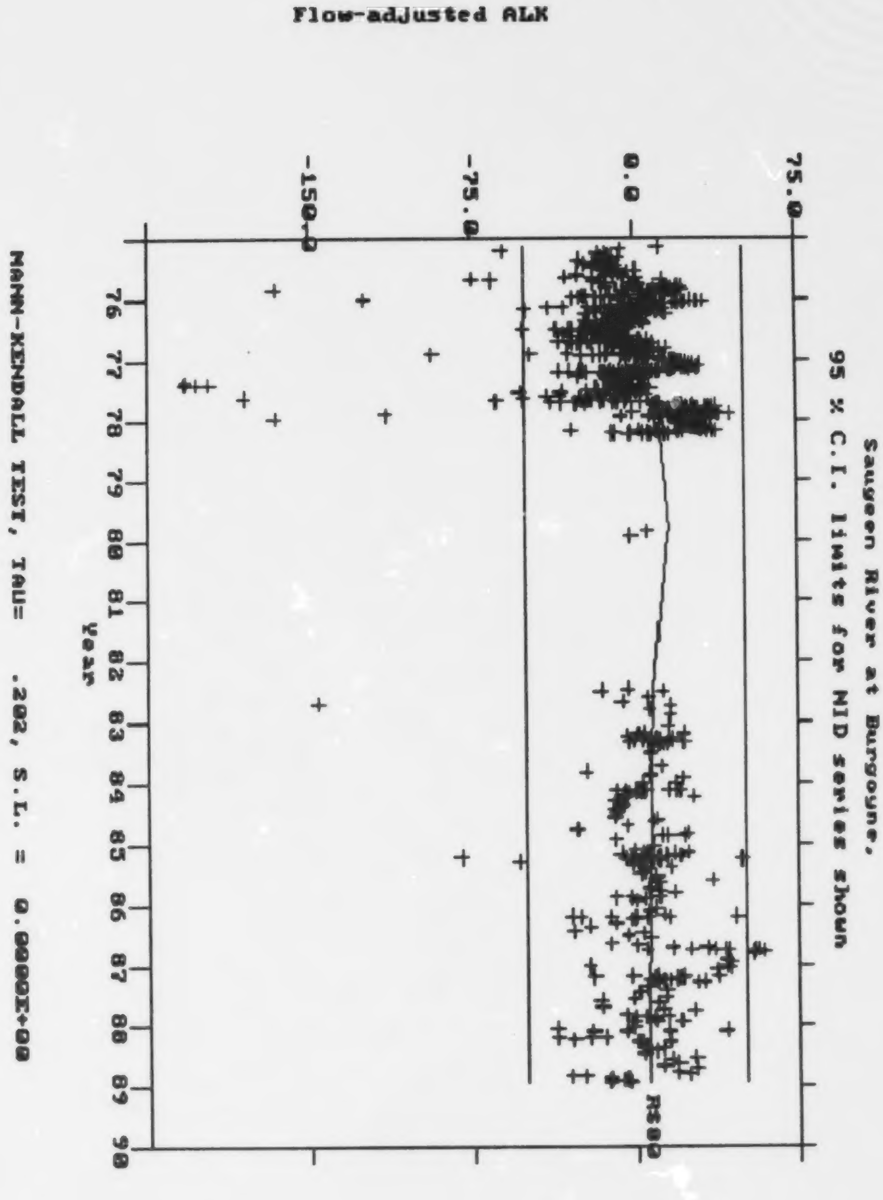
(i) 1975-1977 with heavy sampling
(ii) 1982-1989.with relatively light sampling

Almost no data for 1978-1981.

Saugeen.ALK.2

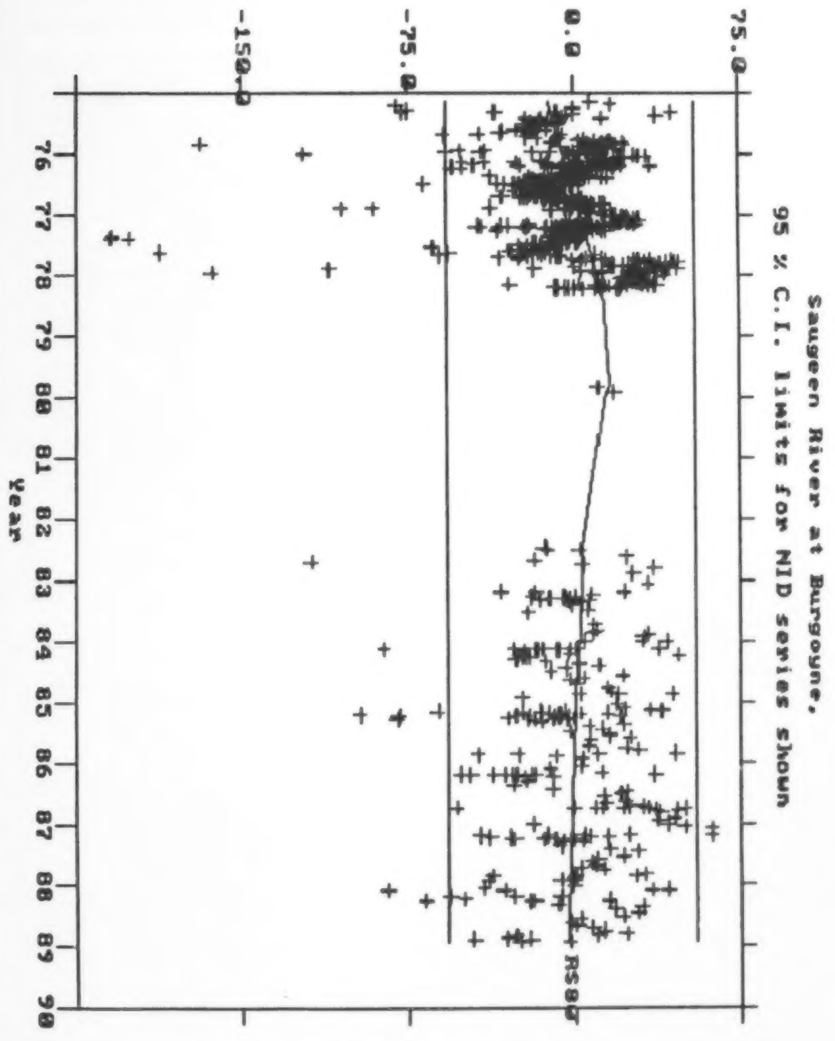


Saugeen.ALK.3



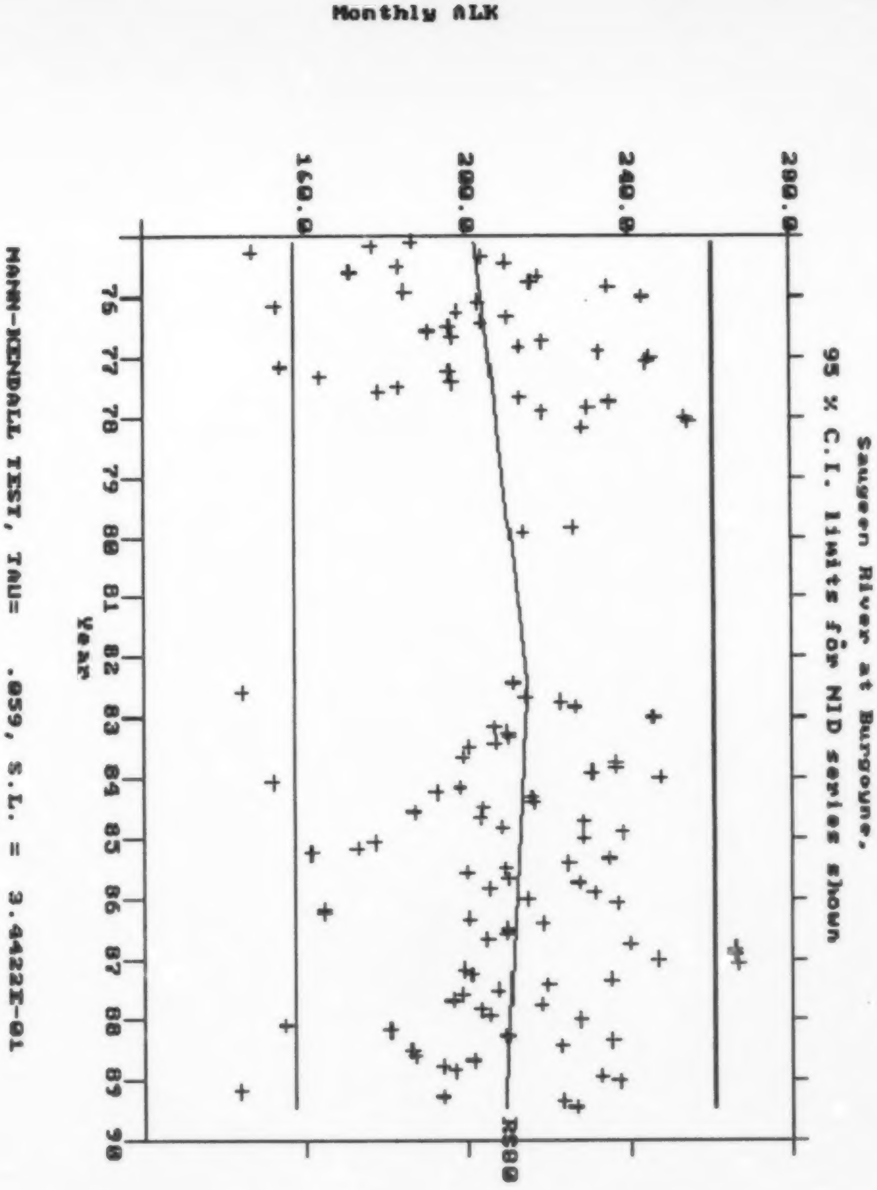
Detrended

Flow-adjusted ALK



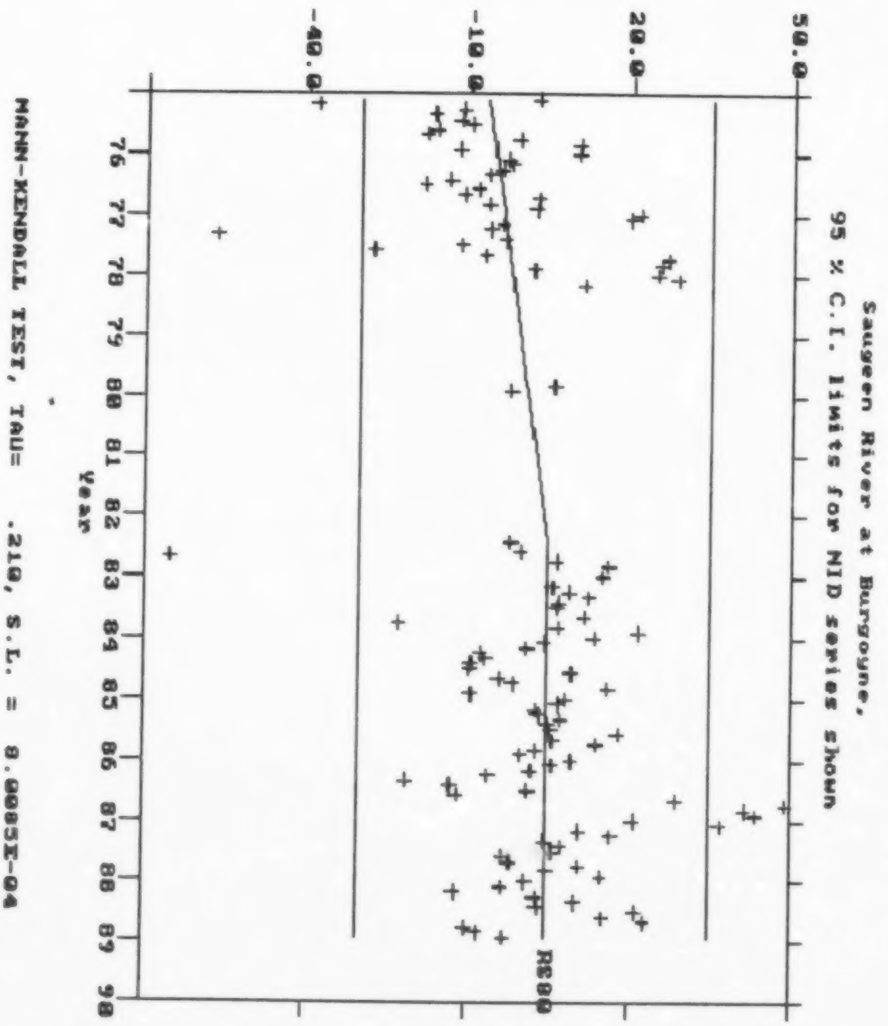
MANN-KENDALL TEST, TAU= .068, S.L. = 1.1573E-03

Saugeen.ALK.5



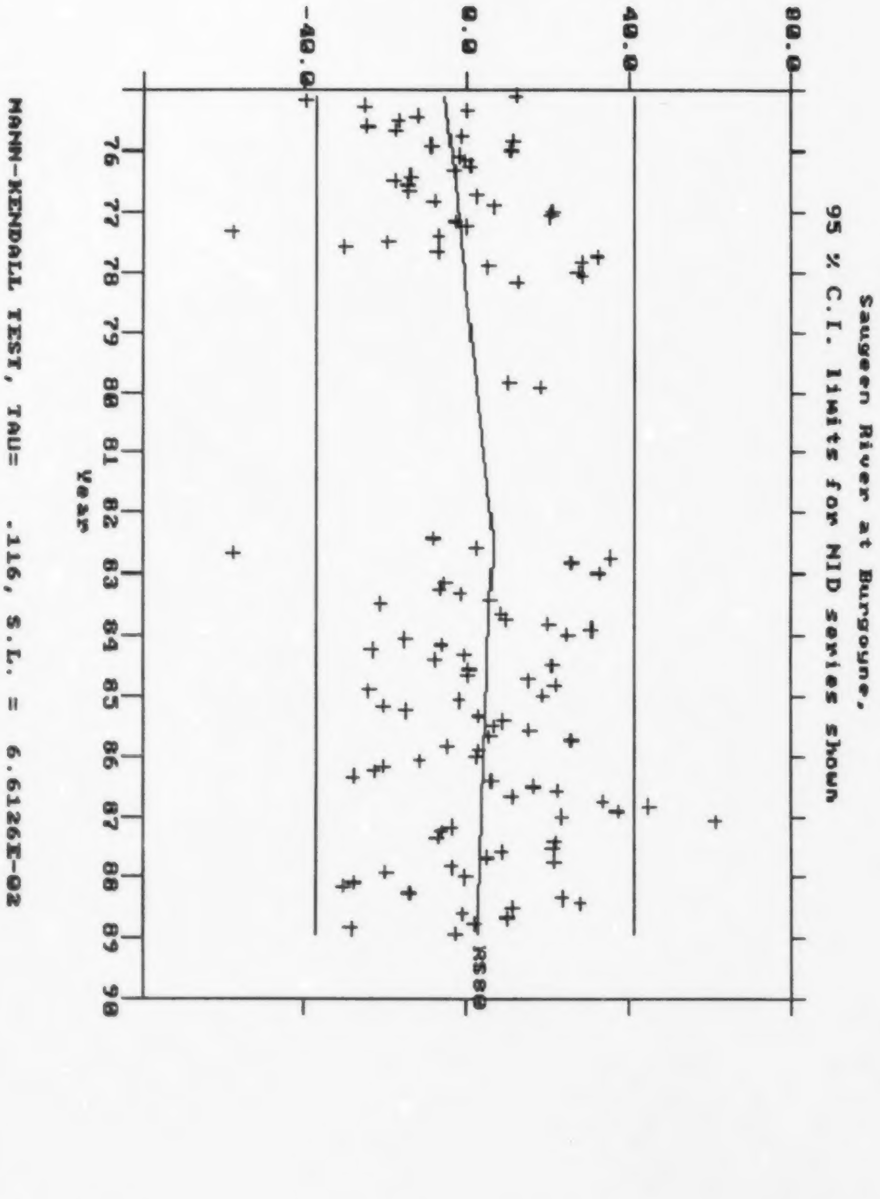
Saugeen.ALK.6

Monthly Flow adjusted ALK

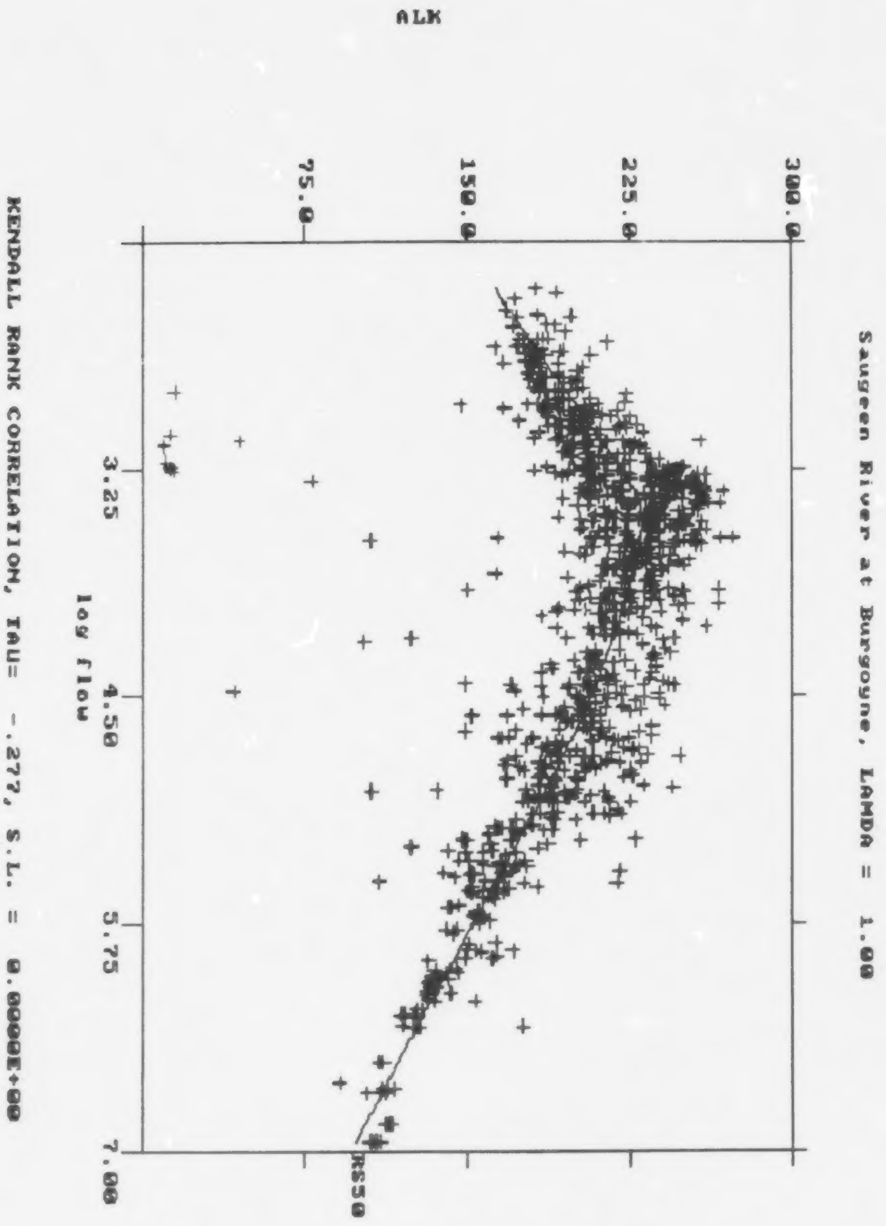


Saugeen.ALK.7

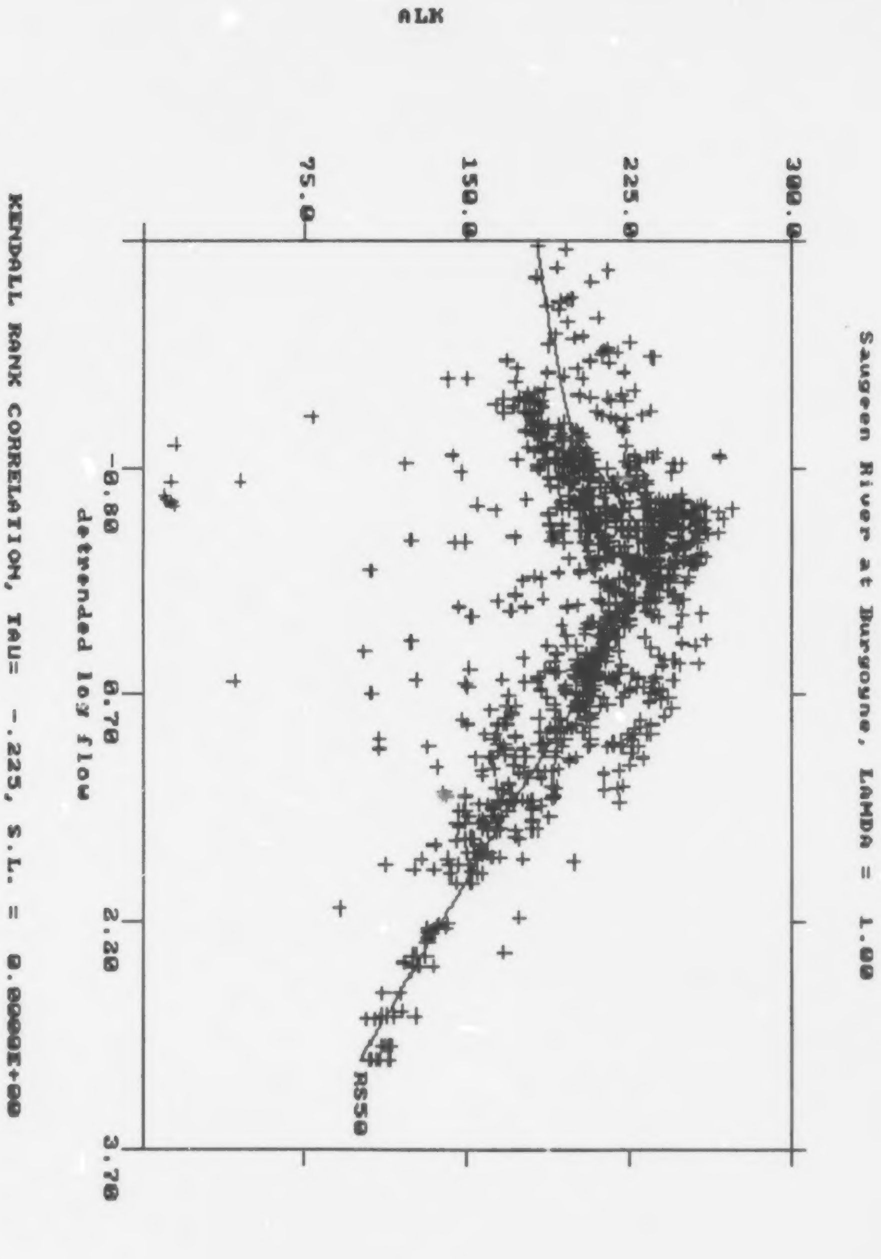
Monthly Flow-detrended ALK



Saugeen.ALK.8

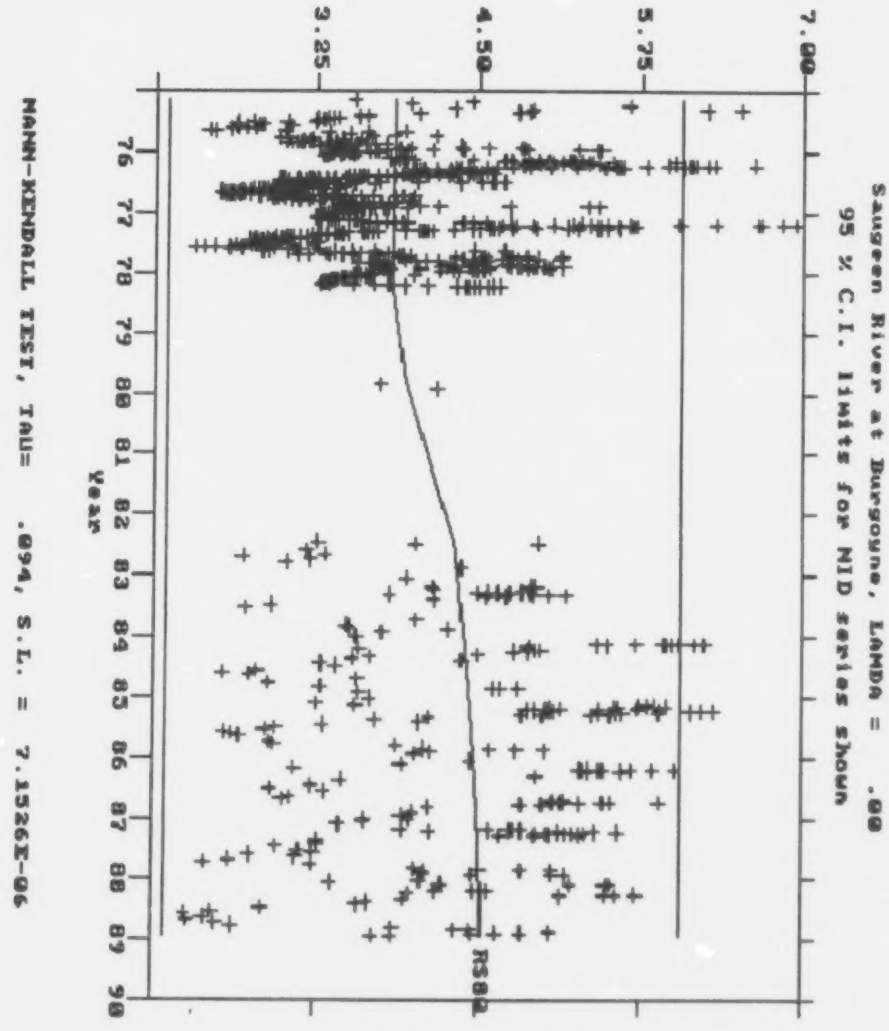


Saugeen.ALK.9



Saugeen.ALK.10

TRANSFORMED flow @ ALK



Saugeen.ALK.11

```
    Trend tests for mean monthly data


    Site: Saugeen River at Burgoyne,

    parameter: ALK

    Basic data - not adjusted for flow


    Mann-Kendall Trend Test
          tau           Significance Level
        .05856               3.44217E-01


    Ordinary Spearman Trend Test
          rho           Significance Level
        .09251               3.12911E-01


    Seasonal Mann-Kendall Trend Test
    Score          Variance          Significance Level
      69.             1521.0                 7.68554E-02


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    9 10  7  1  3  6  6  4  2  5  9  8

         rho          Significance Level
      .11247               2.19846E-01
```

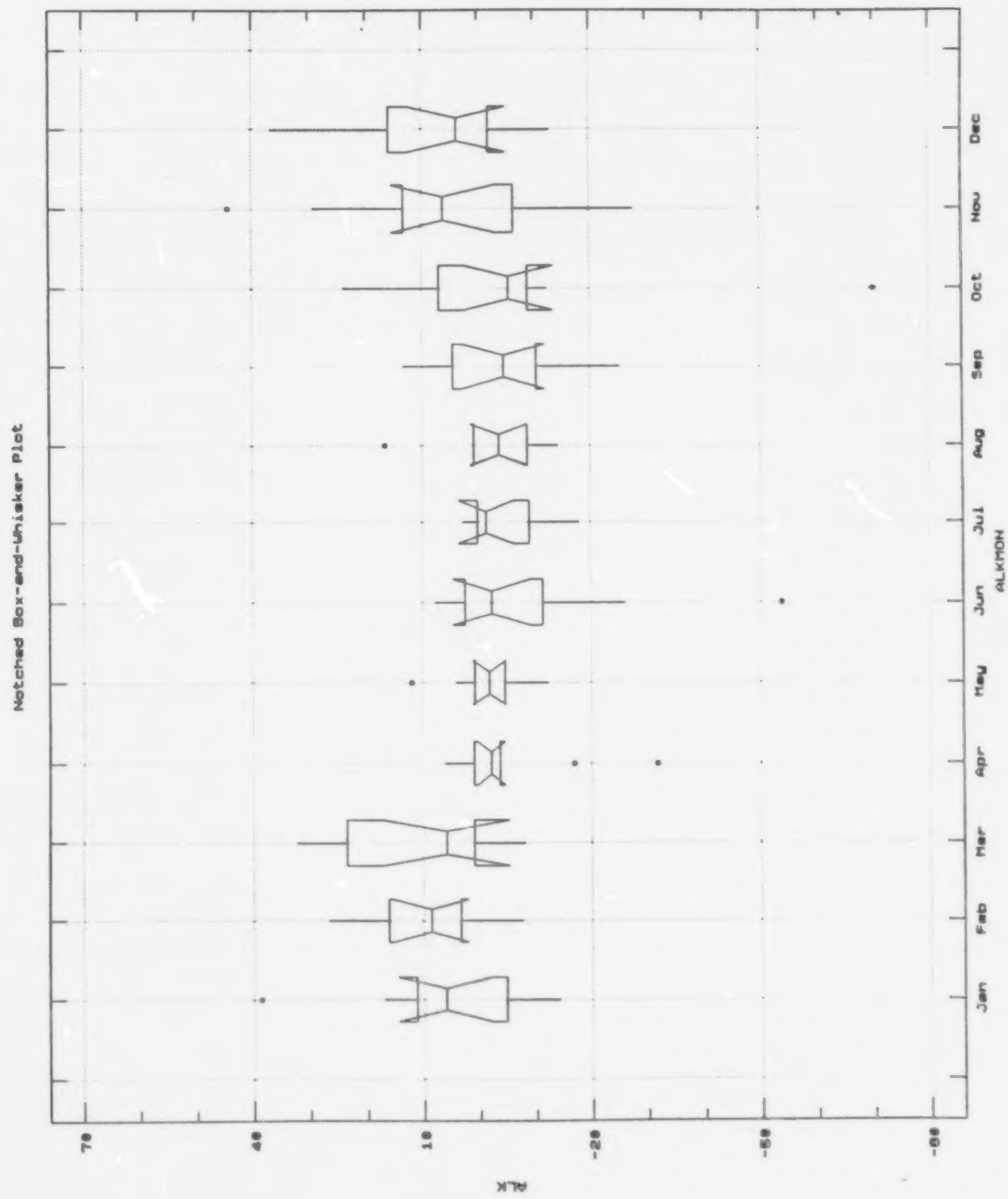
SAUGEEN.ALK.12

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of ALK by ALKMON
--------------------------------------------------------------------------------
Level          Sample Size     Average Rank
--------------------------------------------------------------------------------
  1               10             84.7000  9
  2                9            101.222  10
  3               11             70.4545  7
  4               10             17.7000  1
  5               10             31.5000  3
  6               11             69.3636  6
  7                9            67.6667  6
  8                9            42.1111  4
  9               10             26.2000  2
 10               10             52.2000  5
 11               11             83.9091  9
 12               10             77.7000  8
--------------------------------------------------------------------------------
Test statistic = 61.4954  Significance level  = 4.88503E-9
```

Saugeen.ALK.13

```
    Trend tests for mean monthly data


    Site: Saugeen River at Burgoyne,

    parameter: ALK

    Flow-adjusted Data


    Mann-Kendall Trend Test
          tau          Significance Level
        .21037              8.00848E-04


    Ordinary Spearman Trend Test
          rho          Significance Level
        .32453              5.30124E-04


    Seasonal Mann-Kendall Trend Test
    Score          Variance          Significance Level
     106.             1342.0                 3.80921E-03


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:   1  2  3  4  5  6  7  8  9 10 11 12
  Rank:   3  5  4  2  2  1  1  1  2  2  3  3

         rho         Significance Level
      .33865              2.99454E-04
```

Saugeen.ALK.14



SAUGEEN.ALK.15

```
------------------------------------------------------------
Kruskal-Wallis analysis of ALK by ALKMON
------------------------------------------------------------
Level            Sample Size     Average Rank
------------------------------------------------------------
  1                   9             70.8889 3
  2                   9             80.1111 5
  3                  10             78.6000 4
  4                   9             46.1111 2
  5                   9             49.4444 2
  6                  10             43.5000 1
  7                   9             42.4444 1
  8                   9             42.7778 1
  9                  10             46.7000 2
 10                  10             49.6000 2
 11                  11             69.9091 3
 12                  10             73.1000 3
------------------------------------------------------------
Test statistic = 21.8214  Significance level  = 0.025794
```

Saugeen.ALK.16

```
    Trend tests for mean monthly data


    Site: Saugeen River at Burgoyne,

    parameter: ALK

    Flow-adjusted Data


    Mann-Kendall Trend Test
          tau          Significance Level
        .11609              6.61255E-02


    Ordinary Spearman Trend Test
          rho          Significance Level
        .16988              6.97037E-02


    Seasonal Mann-Kendall Trend Test
    Score          Variance          Significance Level
      66.             1342.0                 7.16023E-02


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:   1  2  3  4  5  6  7  8  9 10 11 12
  Rank:   4  5  4  1  1  2  3  3  2  2  6  4

         rho         Significance Level
      .18774              4.50176E-02
```

SAUGEEN.ALK.17

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of ALK by ALKMON
--------------------------------------------------------------------------------
Level          Sample Size    Average Rank
--------------------------------------------------------------------------------
 1               9          66.2222  4
 2               9          81.1111  5
 3              10           67.1000 4
 4               9          28.6667  1
 5               9          30.1111  1
 6              10           49.7000 2
 7               9          59.5556  3
 8               9          56.0000  3
 9              10           46.9000 2
 10              10           48.8000 2
 11              11           87.0000 6
 12              10           69.3000 4
--------------------------------------------------------------------------------
Test statistic = 30.8913  Significance level  = 1.14617E-3
```

Saugeen.CND

Saugeen River at Burgoyne

Conductivity

Table of Contents: Saugeen.CND

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs CND

(9) Scatter and smooth of detrended-flow vs CND

(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box-and-whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Summary and Conclusions

Saugeen River - CND

Data Transformation: none

Seasonality: Very strong in unadjusted data and flow-adjusted data but less strong in detrended-flow adjusted data.

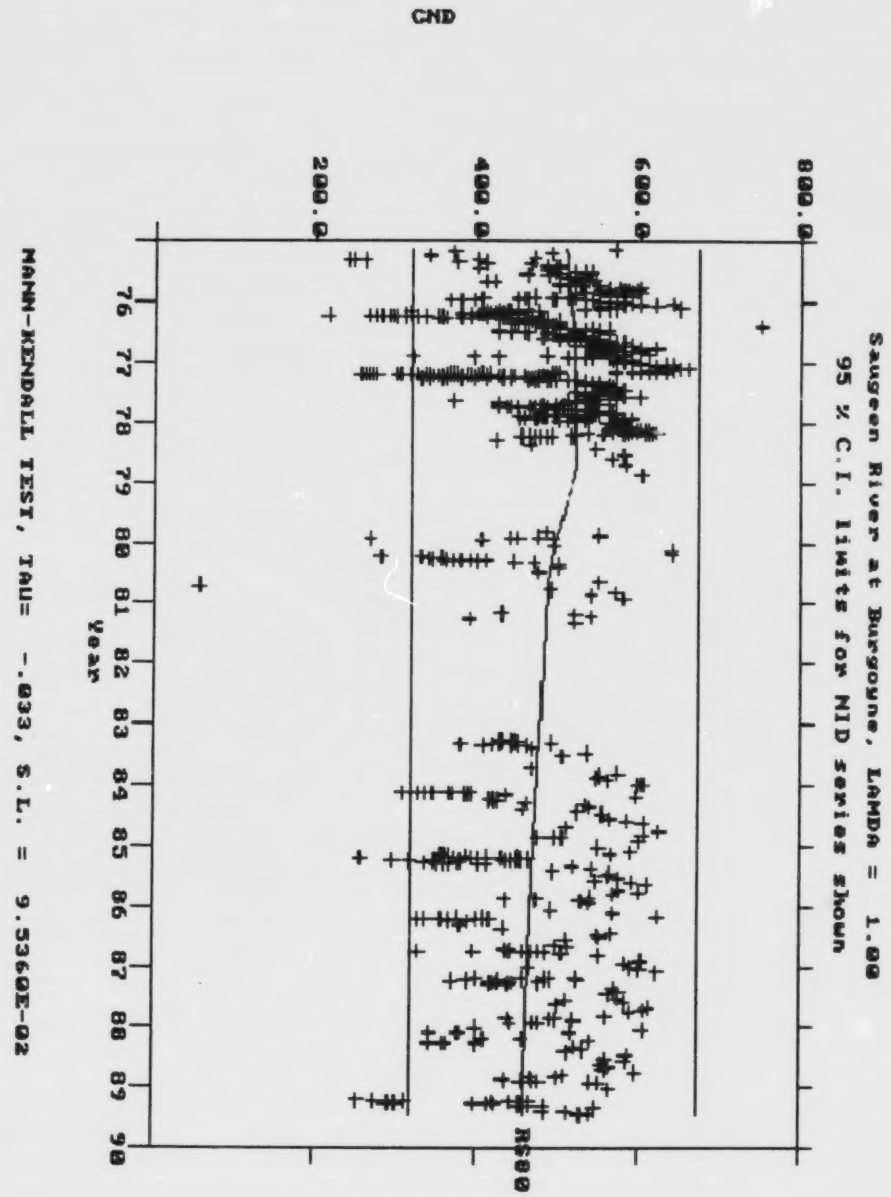
Flow-Concentration Relationship:negative or decreasing relatioship with flow.

Outliers: one extreme outlier. The value 56.0 reported on September 15, 1980. Perhaps a digit was dropped and the true value is 560. Since robust procedures are being used this will affect the analysis anyway.

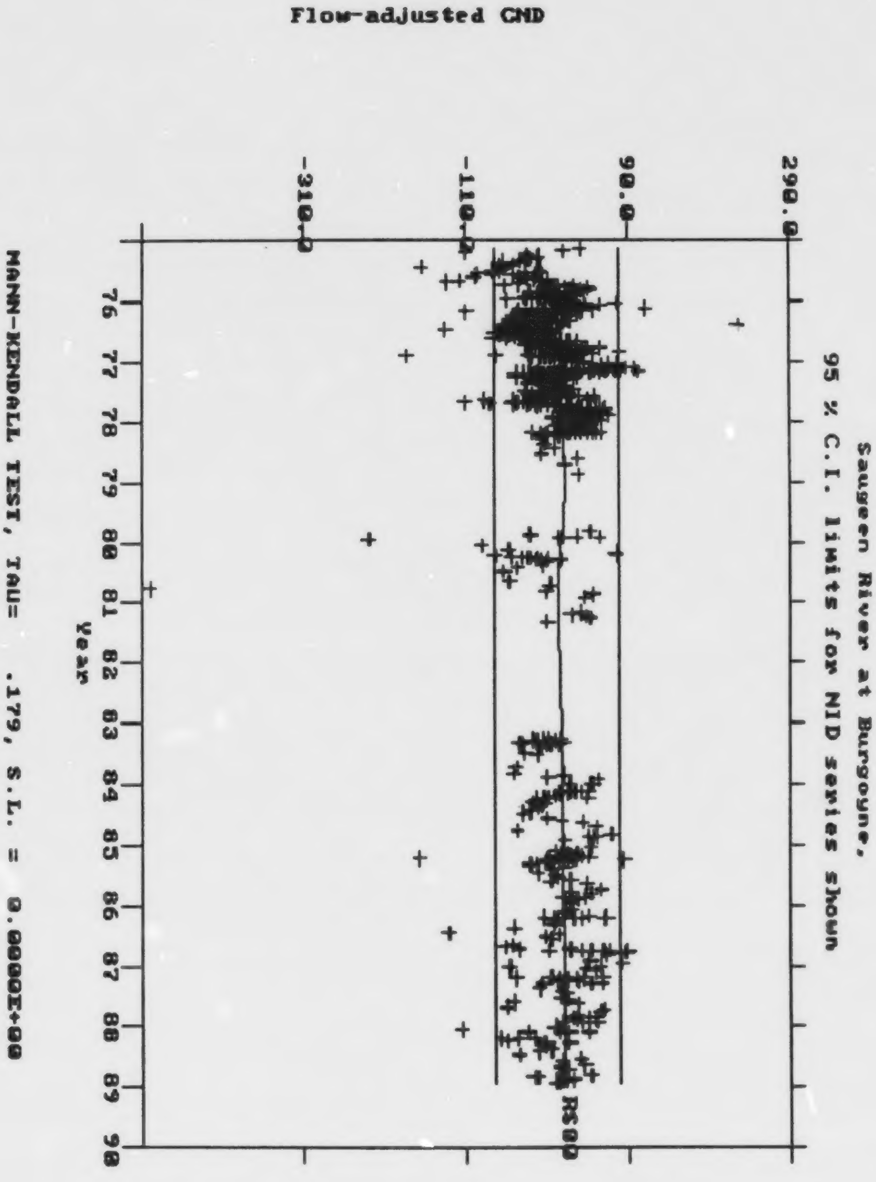
Trend: Tests are not significant in the unadjusted or detrended-flow-adjusted data but are all significant at 5% in the flow-adjusted data. Sampling bias is removed by using the detrended-flow-adjustment procedure.

Other: Note that the data are comprised of basically three chunks:
- (i) 1975-1979 with heavy sampling
- (ii) 1980-1981 with relatively light sampling
- (iii) 1982-1989.with relatively moderate sampling

Saugeen.CND.2



Saugeen.CND.3



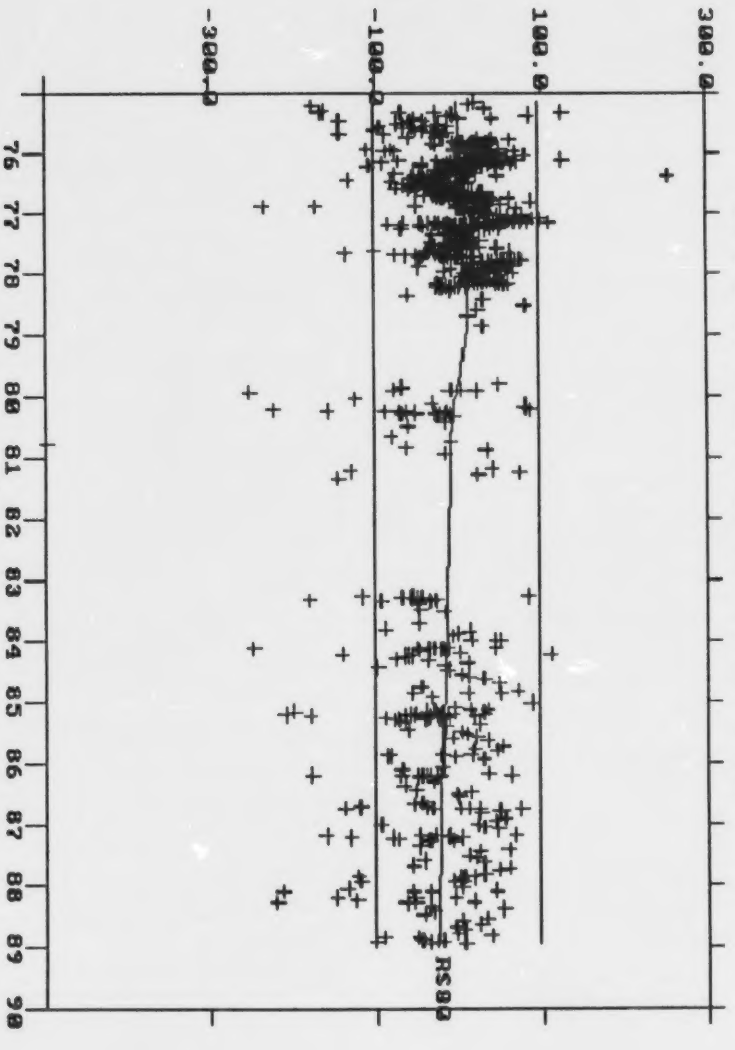
Saugeen.CND.4

Detrended

Flow-adjusted CND

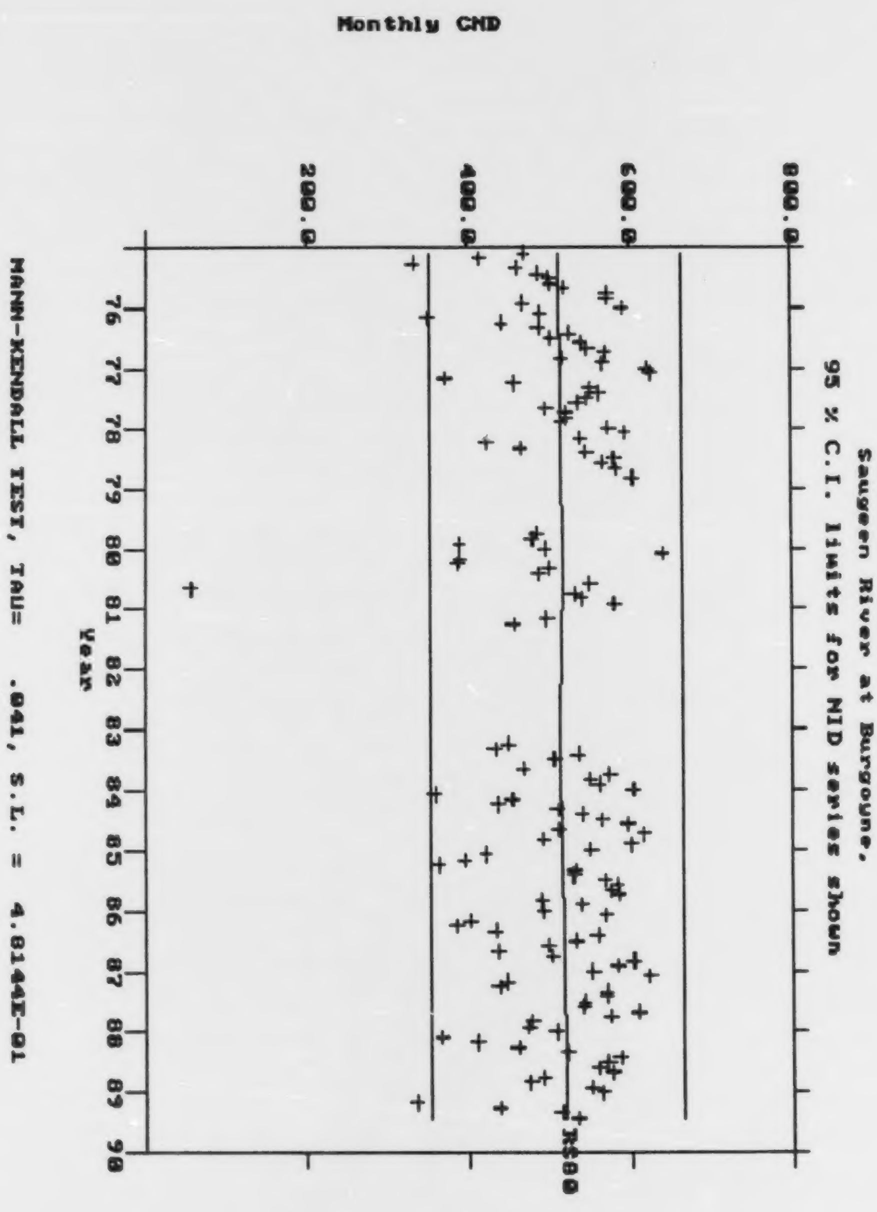
Saugeen River at Burgoyne,

95 % C.I. limits for NID series shown



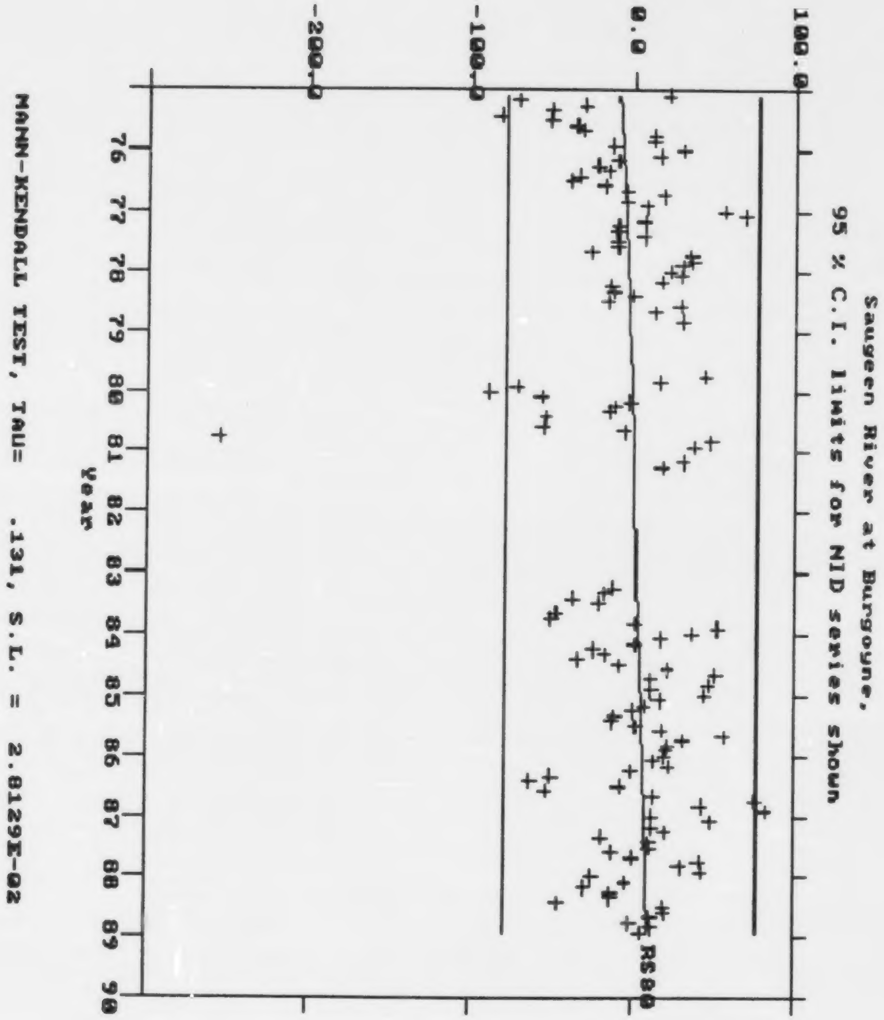
MANN-KENDALL TEST, TAU= -.063, S.L. = 1.7250E-03

Saugeen.CND.5



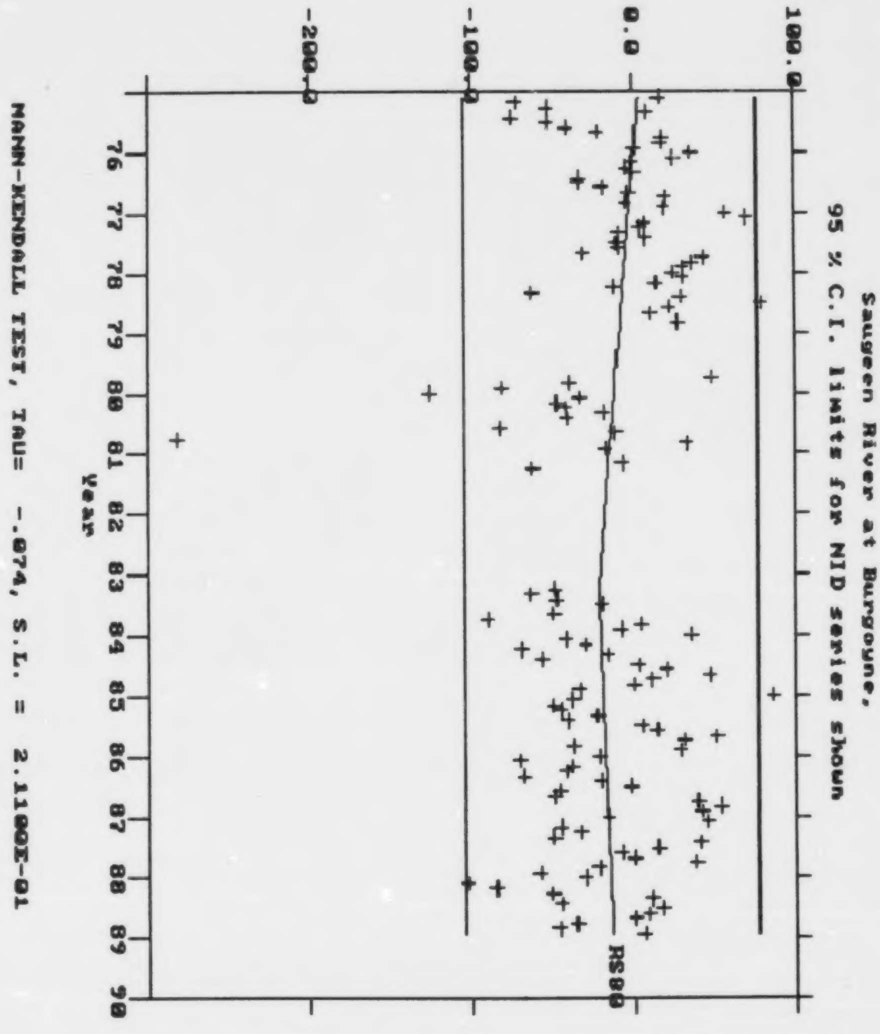
Saugeen.CND.6

Monthly Flow adjusted CND



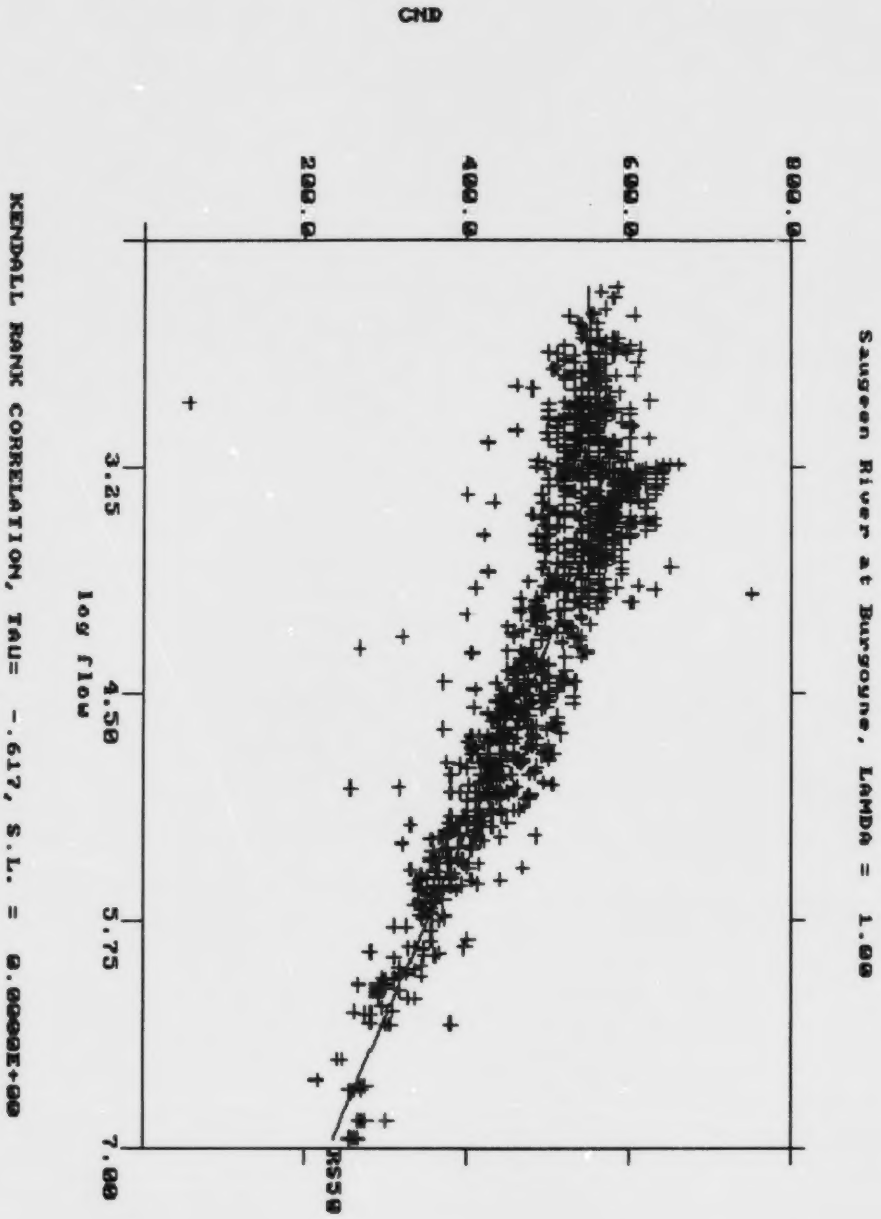
Saugeen.CND.7

Monthly Flow-detrended CND

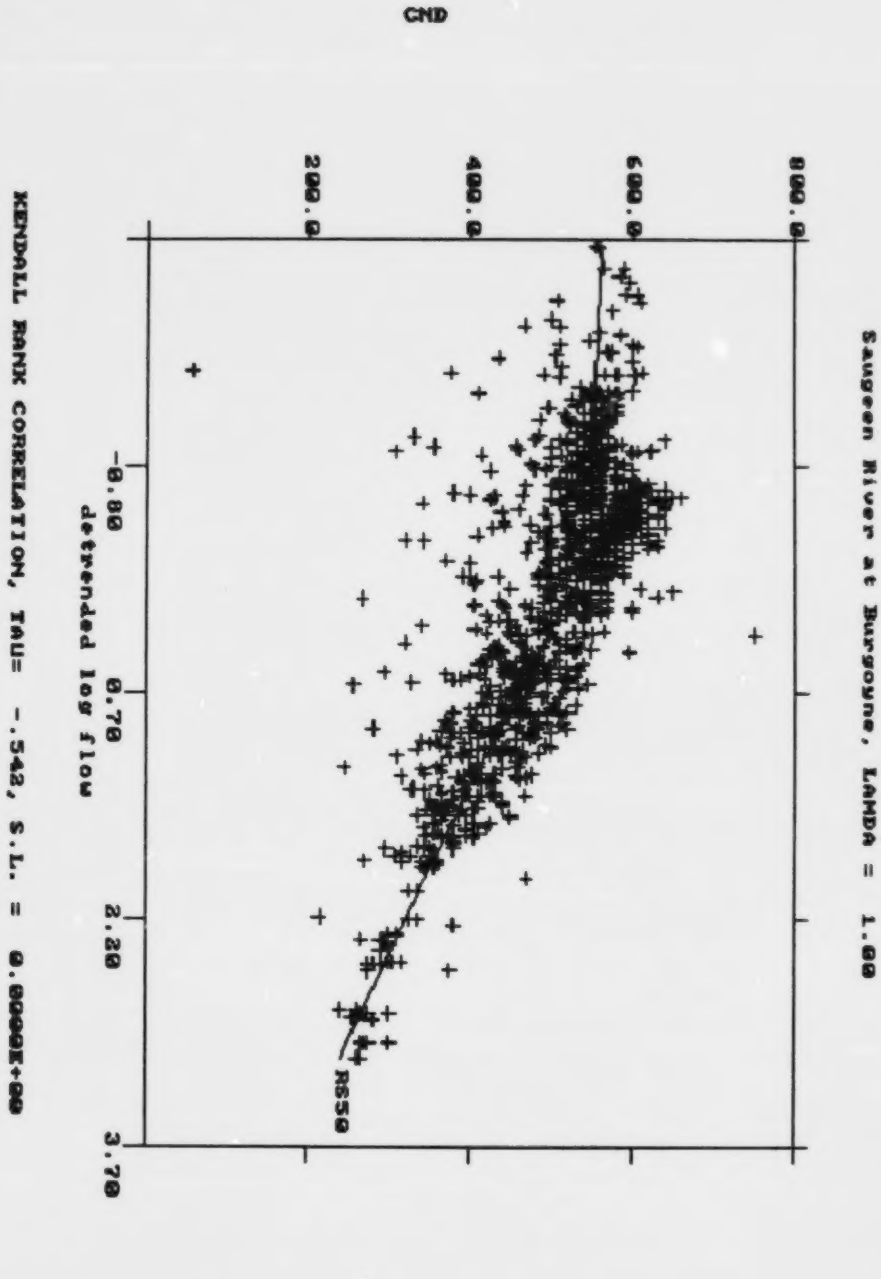


MANN-KENDALL TEST, TAU= -.074, S.L. = 2.1180E-01

Saugeen.CND.8

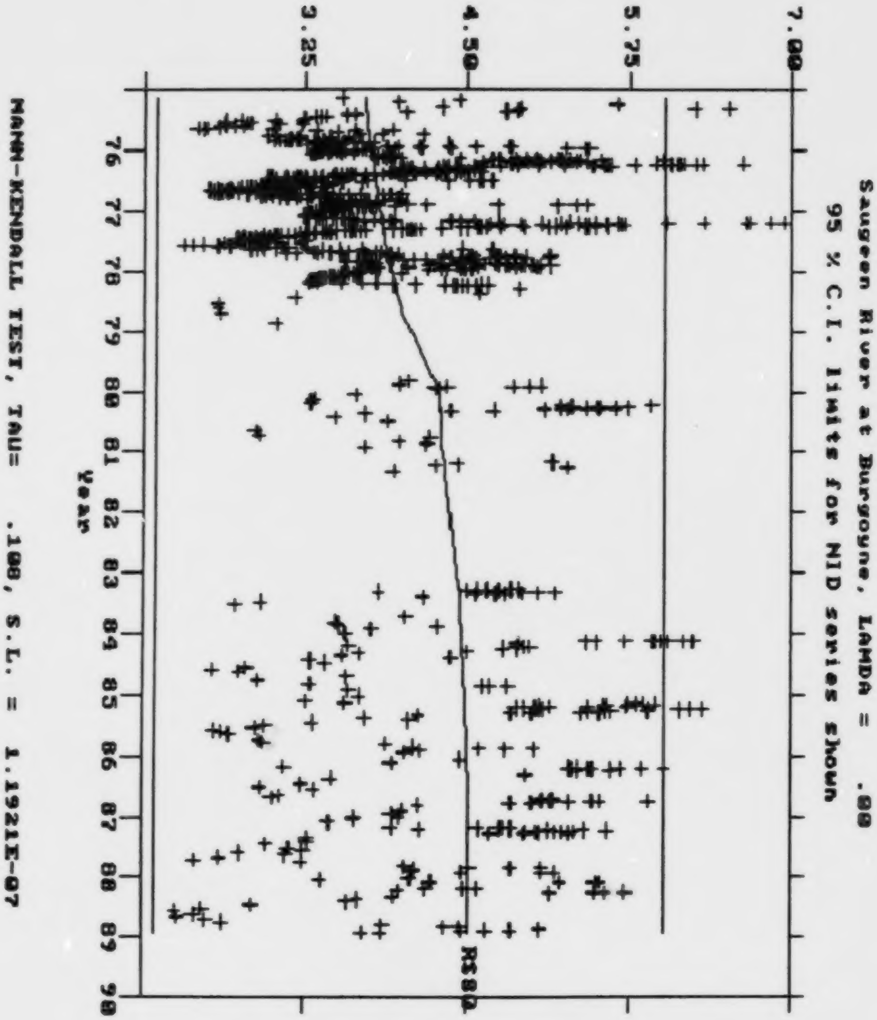


Saugeen.CND.9



Saugeen.CND.10

TRANSFORMED flow @ CND



Saugeen.CND.11

```
      Trend tests for mean monthly data


      Site: Saugeen River at Burgoyne,

      parameter: CND

      Basic data - not adjusted for flow


      Mann-Kendall Trend Test
            tau          Significance Level
          .04121              4.81437E-01


      Ordinary Spearman Trend Test
            rho          Significance Level
          .05230              5.46382E-01


      Seasonal Mann-Kendall Trend Test
      Score          Variance          Significance Level
        57.             2112.3                  2.14899E-01


      Spearman Trend Test Partialling Out Seasonality

      Seasonal rankings:
  Season:   1  2  3  4  5  6  7  8  9 10 11 12
    Rank:   5  7  6  2  1  3  6  6  6  5  7  4

           rho         Significance Level
        .05547              5.22344E-01
```

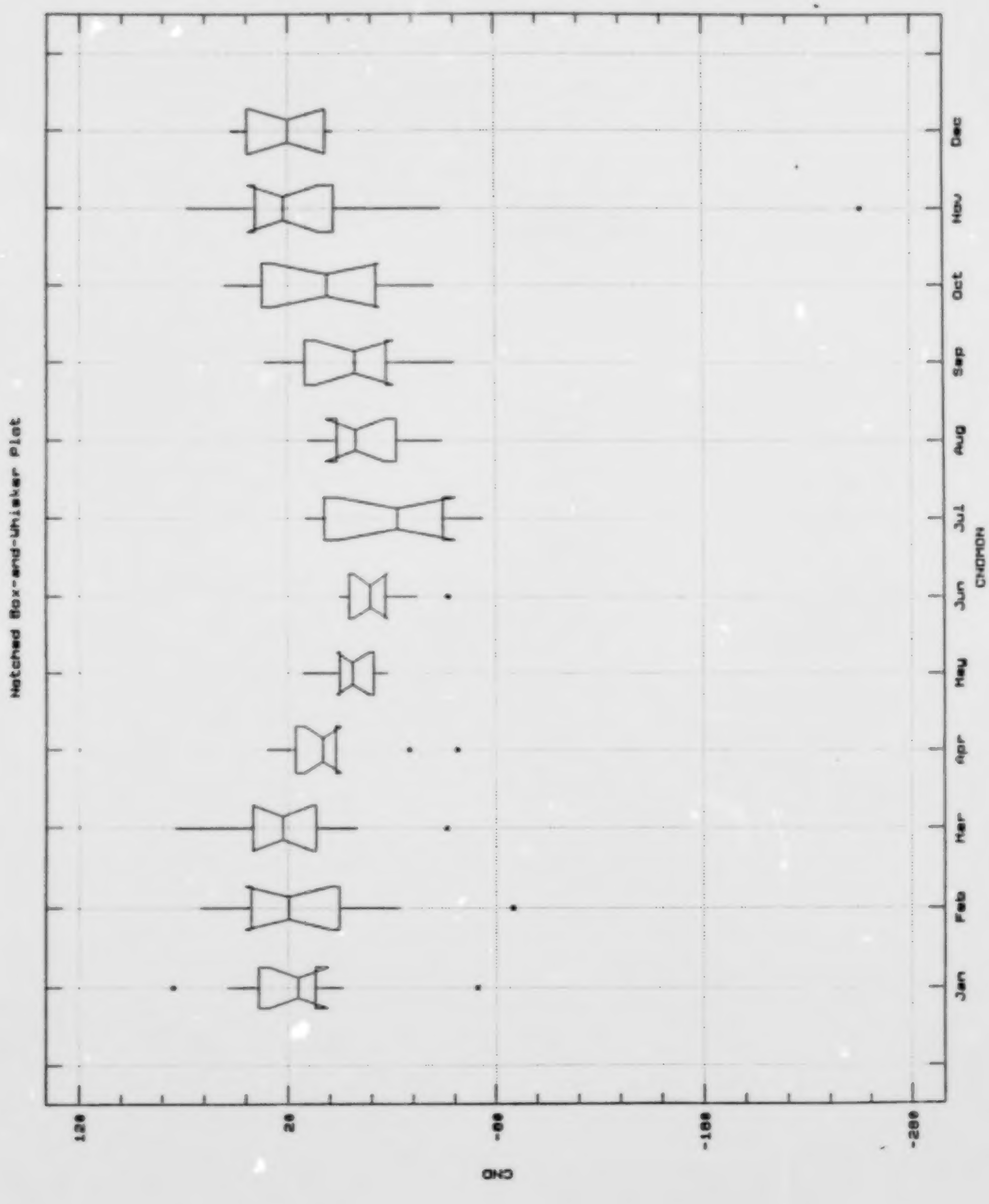
SAUGEEN.CND:12

```
----------------------------------------------------------------------------
Kruskal-Wallis analysis of CND by CNDMON
----------------------------------------------------------------------------
Level        Sample Size   Average Rank
----------------------------------------------------------------------------
  1              10          75.2000  5
  2              10          90.1000  7
  3              12          79.3333  6
  4              13          23.0000  2
  5              12          18.7500  1
  6              12          55.3333  3
  7              10          84.6000  6
  8              10          82.2000  6
  9              11          84.8182  6
 10              11          73.0909  5
 11              12          90.9167  7
 12              11          68.7273  4
----------------------------------------------------------------------------
Test statistic = 52.2347  Significance level  = 2.4721E-7
```

```
Trend tests for mean monthly data

Site: Saugeen River at Burgoyne,

parameter: CND

Flow-adjusted Data

Mann-Kendall Trend Test
      tau          Significance Level
    .13057              2.81295E-02

Ordinary Spearman Trend Test
      rho          Significance Level
    .19839              2.47985E-02

Seasonal Mann-Kendall Trend Test
Score          Variance          Significance Level
 107.             1882.3                 1.36540E-02

Spearman Trend Test Partialling Out Seasonality

Seasonal rankings:
    Season:    1  2  3  4  5  6  7  8  9 10 11 12
      Rank:    6  5  6  4  2  1  1  2  3  4  5  7

       rho          Significance Level
     .21973              1.29209E-02
```

Saugeen.CND.13

SAUGEEN.CND.14



SAUGEEN.CND.15

```
------------------------------------------------------------
Kruskal-Wallis analysis of CND by CNDMON
------------------------------------------------------------
Level                Sample Size     Average Rank
------------------------------------------------------------
  1                        9             87.4444 6
  2                       10             81.4000 5
  3                       11             88.5455 6
  4                       12             68.4167 4
  5                       11             45.6364 2
  6                       11             33.5455 1
  7                       10             33.7000 1
  8                       10             43.7000 2
  9                       11             51.0000 3
 10                       11             66.6364 4
 11                       12             83.2500 5
 12                       11             95.5455 7
------------------------------------------------------------
Test statistic = 42.3962  Significance level  = 1.38286E-5
```

```
    Trend tests for mean monthly data


    Site: Saugeen River at Burgoyne,

    parameter: CND

    Flow-adjusted Data


    Mann Kendall Trend Test
          tau            Significance Level
       -.07437                 2.10996E-01


    Ordinary Spearman Trend Test
          rho            Significance Level
       -.11348                 1.99169E-01


    Seasonal Mann-Kendall Trend Test
    Score          Variance            Significance Level
     -47.             1882.3                      2.78674E-01


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    4  5  3  1  1  2  2  4  3  4  5  4

         rho           Significance Level
      -.11357                1.98815E-01
```

```
------------------------------------------------------------------------
Kruskal-Wallis analysis of CND by CNDMON
------------------------------------------------------------------------
Level          Sample Size    Average Rank
------------------------------------------------------------------------
 1                9           72.8889  4
 2               10           84.6000  5
 3               11           68.4545  3
 4               12           43.3333  1
 5               11           39.3636  1
 6               11           50.2727  2
 7               10           52.9000  2
 8               10           73.0000  4
 9               11           65.3636  3
 10               11           72.5455  4
 11               12           83.5833  5
 12               11           76.8182  4
------------------------------------------------------------------------
Test statistic = 20.1745  Significance level  = 0.0430042
```

Grand.flow

Grand River at Dunnville

Mean Monthly Flow

Table of Contents: Grand.flow

(1) Summary and conclusions

(2) Trace and smooth of mean monthly flow

(3) Trend tests on monthly flow data

(4) Box-and-whisker plot of flow-adjusted data

(5) Kruskal-Wallis test for seasonality and seasonal rankings on flow

Summary and Conclusions

Grand River - flow

Seasonality: very strong

Outliers: none apparent

Trend: There appears to be a slight upward trend in the flows over the period 1972-1989 but it is not statistically significant at 5% on any of the trend tests. However, if the "drought year" 1989 is omitted the trend becomes signicant at less than 1% on the Seasonal Spearman Trend Test and on the Hirsch-Slack Test.

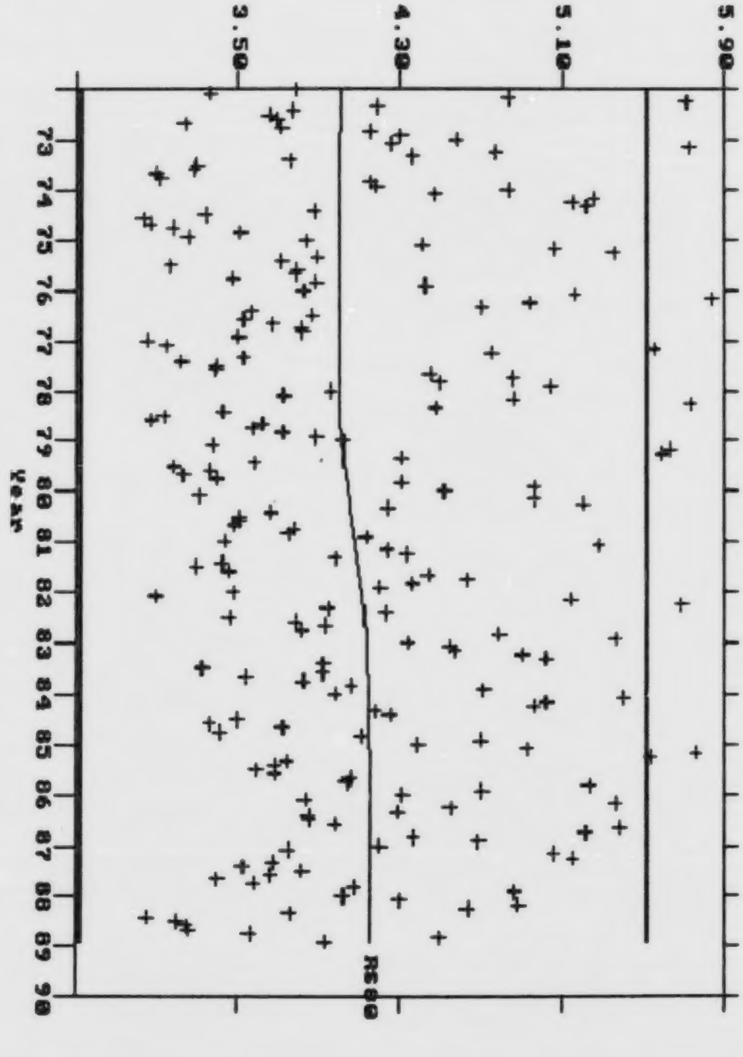
Other:

Grand.FLOW.2

Monthly Flow

Grand River at Dunnville, LAMDA = .00

95 % C.I. limits for NID series shown

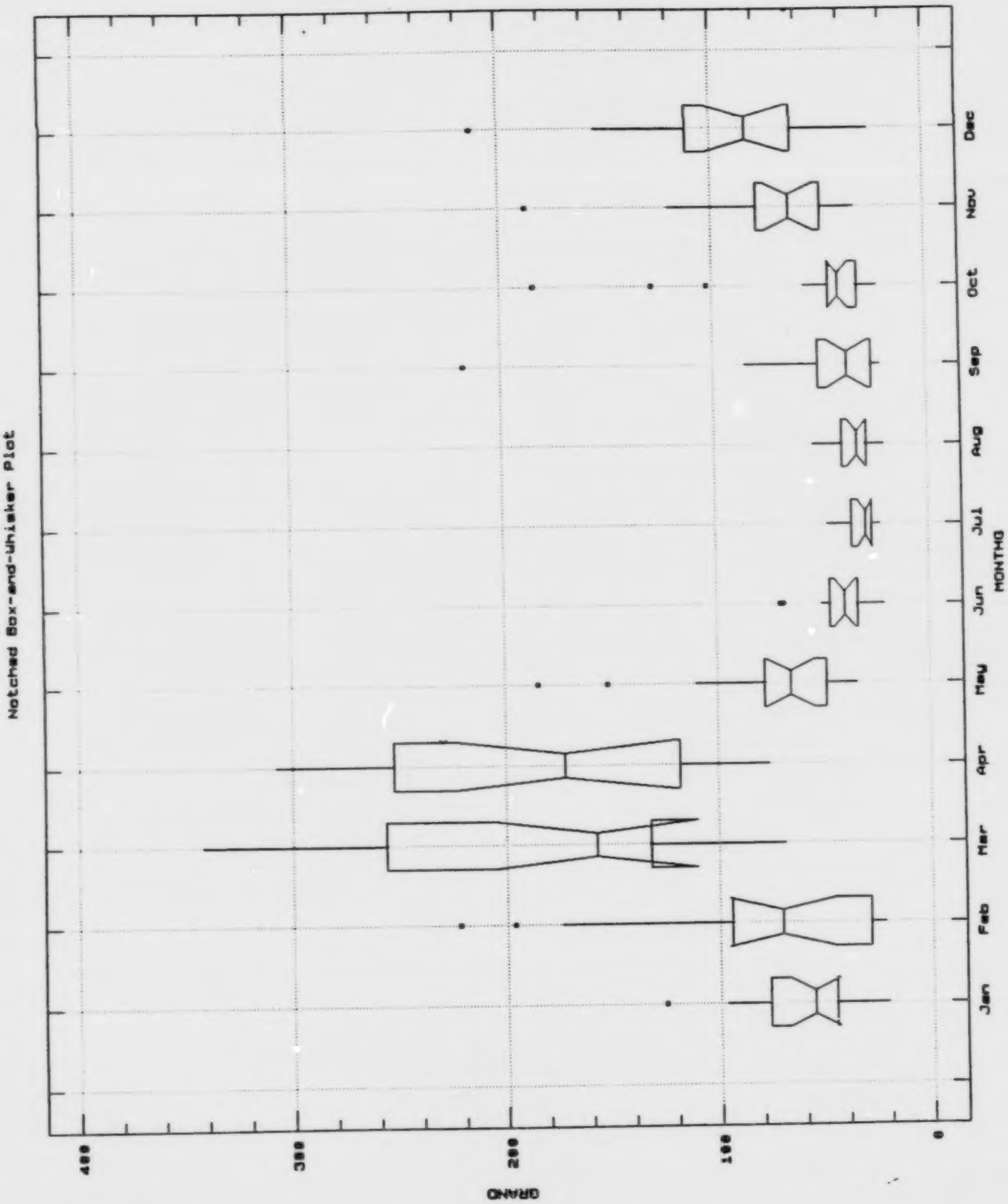


MANN-KENDALL TEST, TAU= .061, S.L. = 1.9323E-01

Grand.FLOW.3

```
     Trend tests for mean monthly data

     Site: Grand River at Dunnville,

     parameter: Mean Monthly Flow

     Basic data - not adjusted for flow

     Mann-Kendall Trend Test
           tau          Significance Level
         .06133              1.93226E-01

     Ordinary Spearman Trend Test
           rho          Significance Level
         .09003              1.99574E-01

     Seasonal Mann-Kendall Trend Test
     Score          Variance          Significance Level
      112.            7072.0                 1.82918E-01

     Spearman Trend Test Partialling Out Seasonality

     Seasonal rankings:
 Season:    1  2  3  4  5  6  7  8  9 10 11 12
   Rank:    3  3  6  6  4  2  1  1  2  2  4  5

          rho         Significance Level
        .11506             1.01147E-01
```

Grand.FLOW.4


Notched Box-and-Whisker Plot
GRAND
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
MONTHS

GRAND.FLOW.5

```
-----------------------------------------------------------
Kruskal-Wallis analysis of GRAND by MONTHG
-----------------------------------------------------------
Level              Sample Size      Average Rank
-----------------------------------------------------------
  1                    17               103.706  3
  2                    17               103.529  3
  3                    17               178.824  6
  4                    17               176.588  6
  5                    17               117.294  4
  6                    17               66.9412  2
  7                    17               41.0000  1
  8                    17               48.8235  1
  9                    17               68.0000  2
 10                    17               77.0000  2
 11                    17               117.471  4
 12                    17               130.824  5
-----------------------------------------------------------
Test statistic = 108.929  Significance level  = 0
```

Grand.NHX

Grand River at Dunnville

Ammonia Nitrogen

Table of Contents: Grand.NHx

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs NHx

(9) Scatter and smooth of detrended-flow vs NHx

(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box-and-whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Summary and Conclusions

Grand River - NHx

Data Transformation: logarithmic

Seasonality: very strong

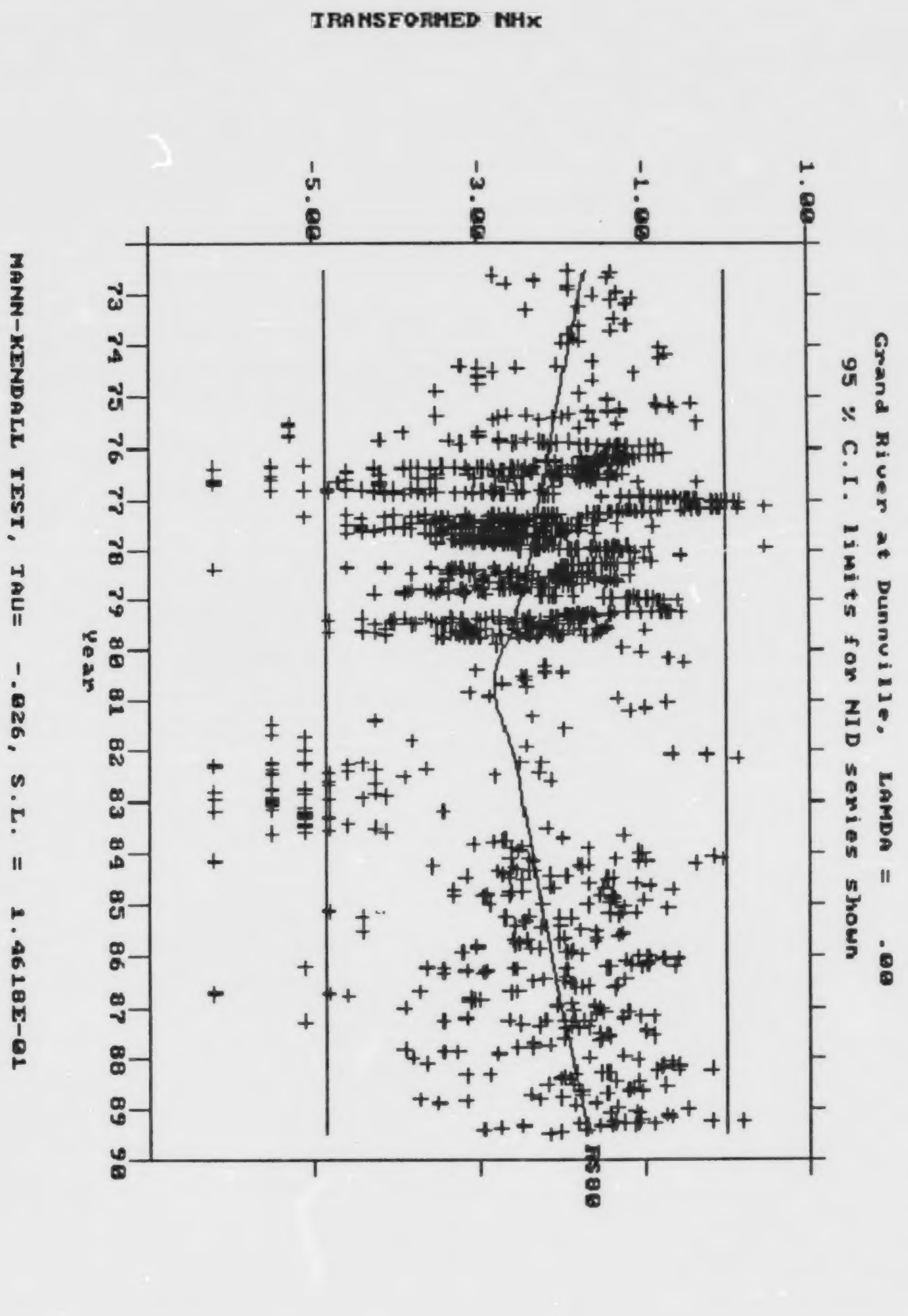
Flow-Concentration Relationship: Positive relationship with flow but slightly U-shaped with detrended-flow.

Outliers: none apparent

Trend: No trend but a very large drop in mean occurs in 1981-1983 with a return to the previous level.

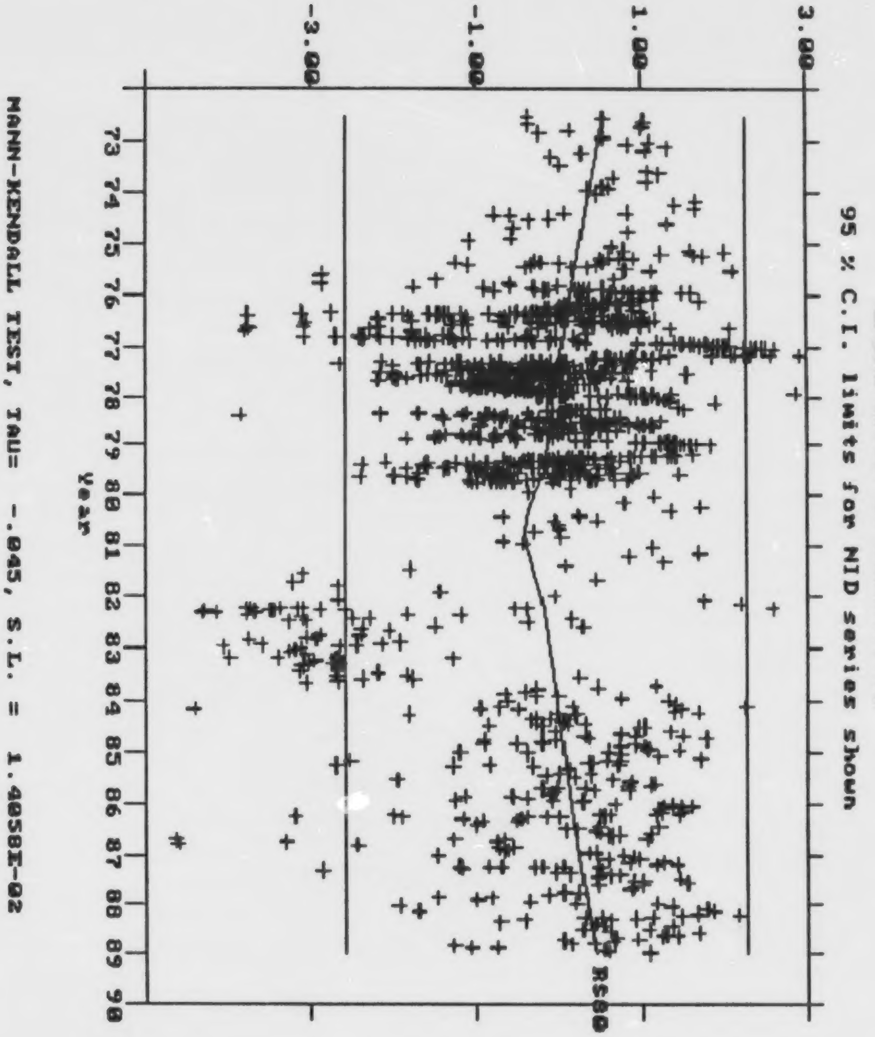
Other:

GRAND.NHX.2


TRANSFORMED NHx
Grand River at Dunnville, LAMDA = .00
95 % C.I. limits for NID series shown
1.00
-1.00
-3.00
-5.00
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Year
RS80
MANN-KENDALL TEST, TAU= -.026, S.L. = 1.4618E-01

GRAND.NHX.3

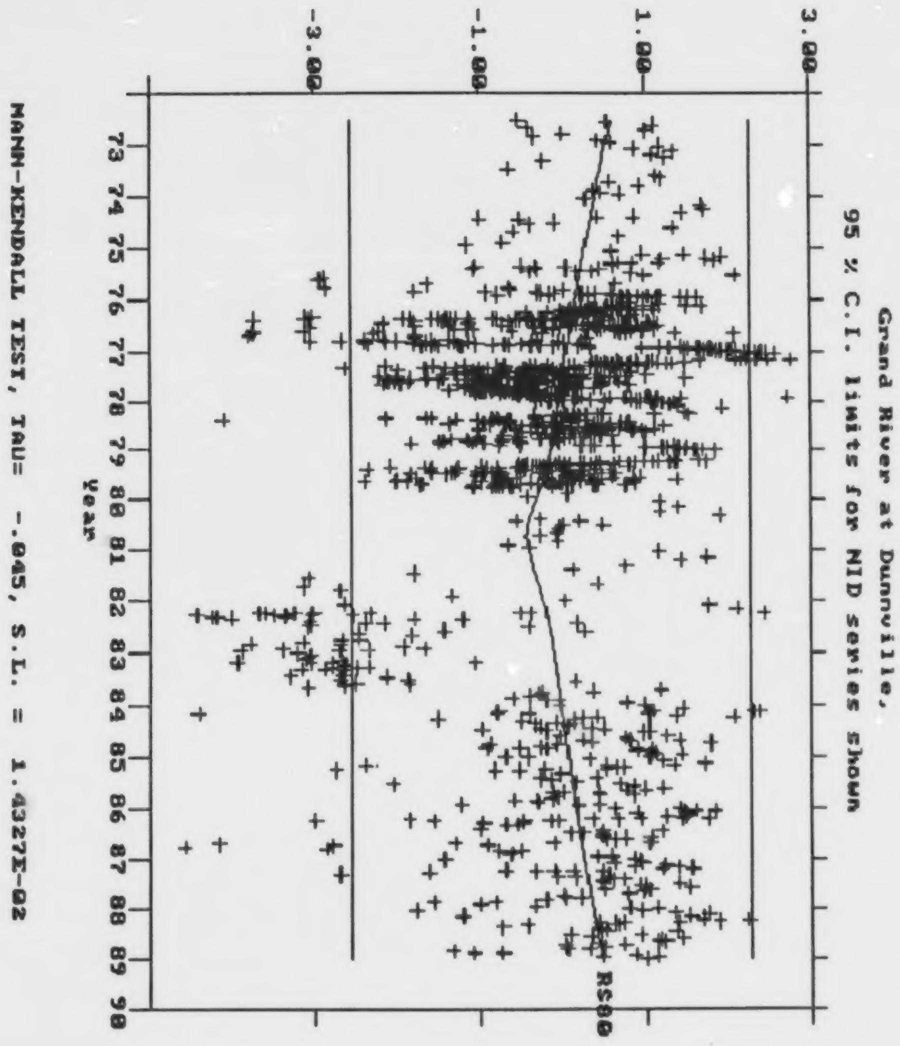
Flow-adjusted NHx



Grand.NHX.4

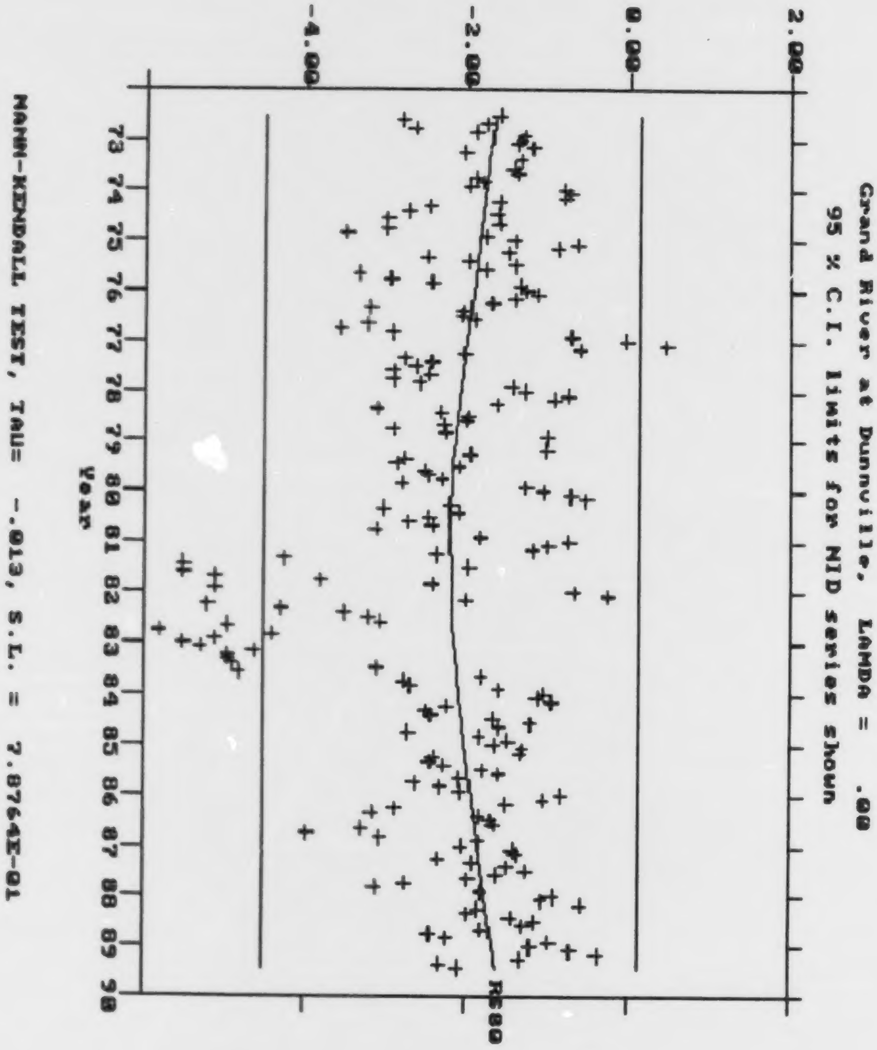
Detrended

Flow-adjusted NHx



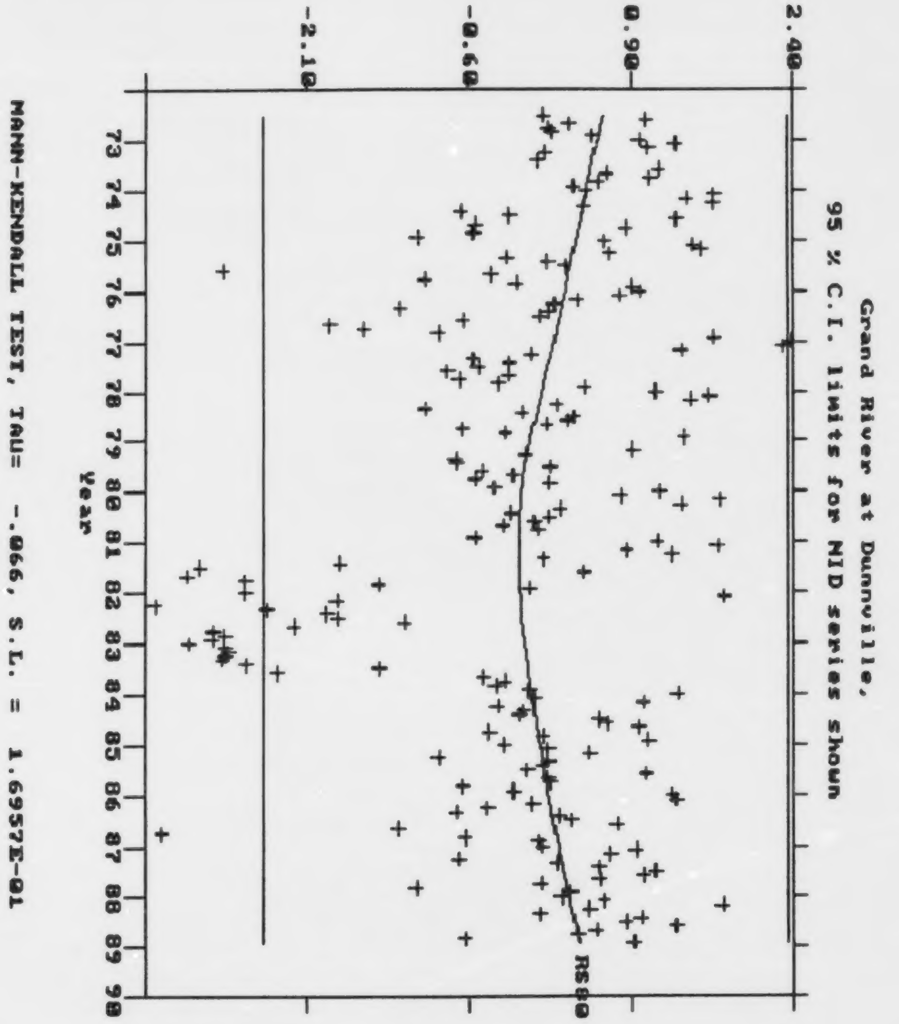
Grand.NHX.5

Monthly NHx



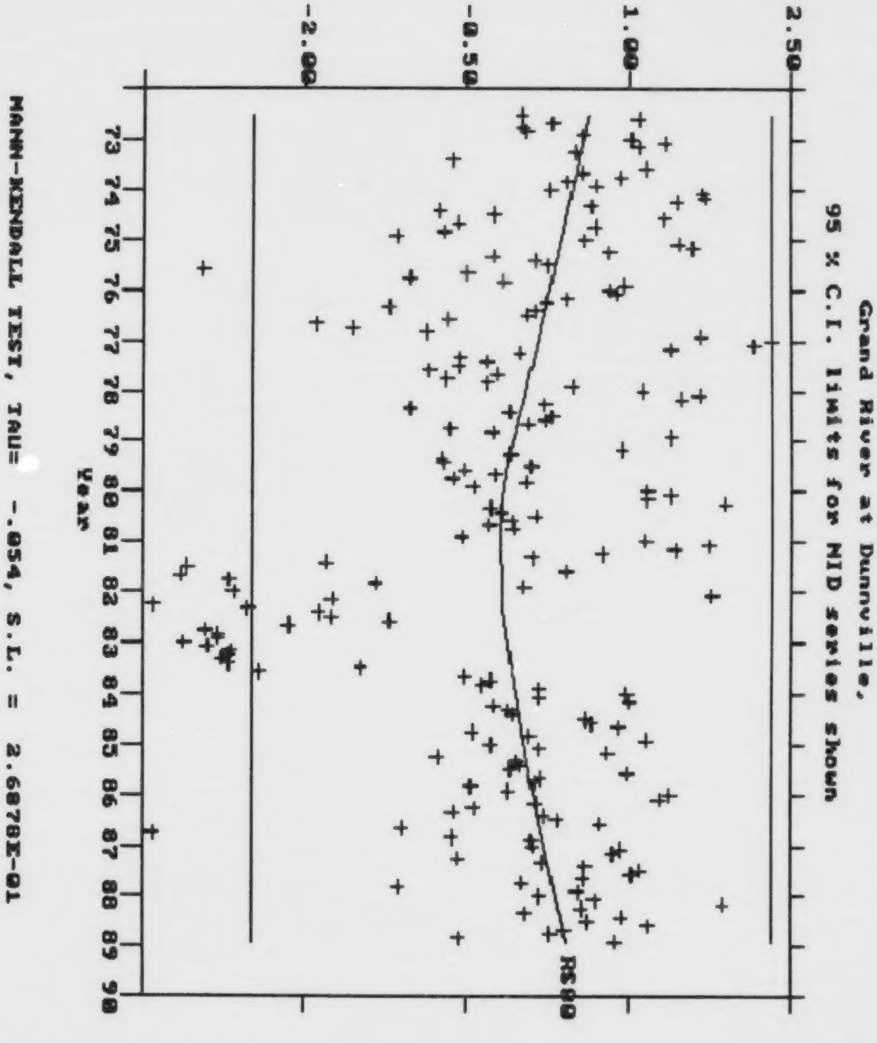
Grand.NHX.6

Monthly Flow adjusted NHx

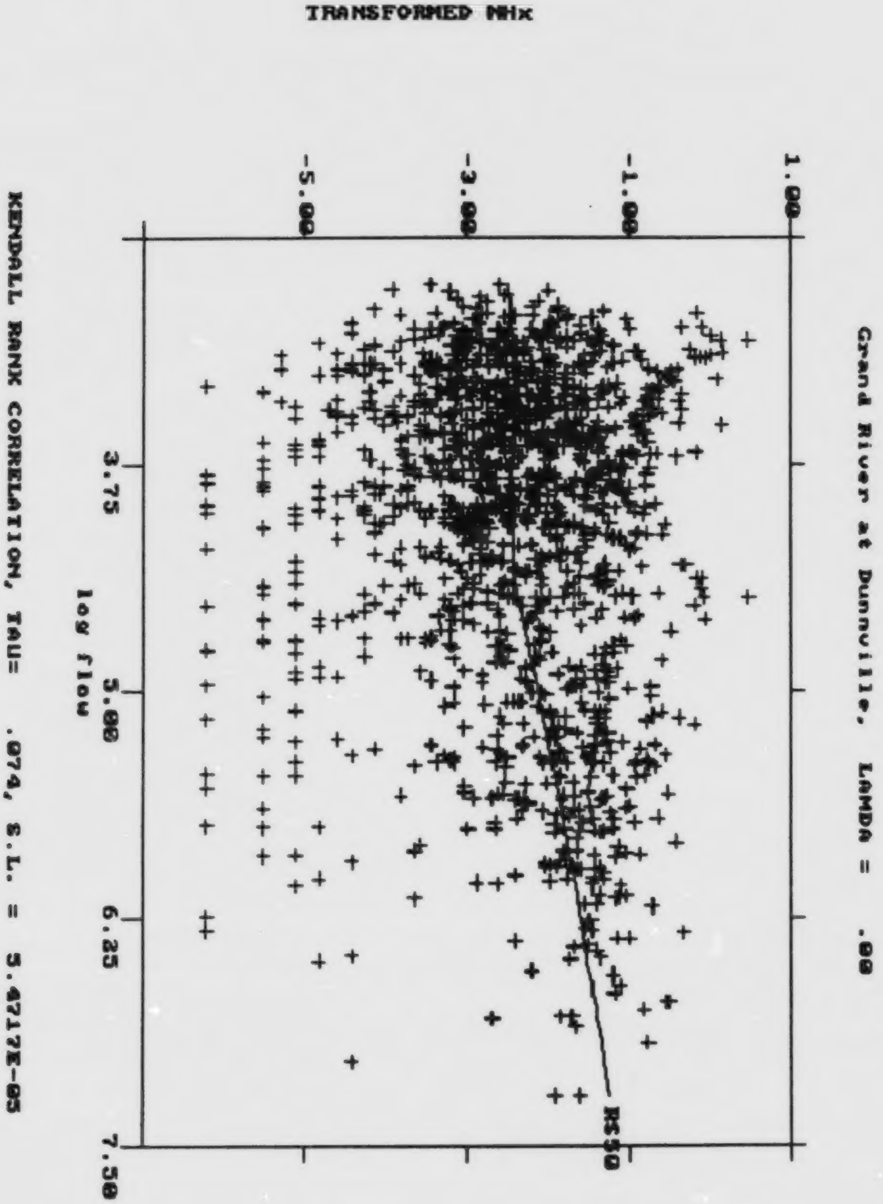


Grand.NHX.7

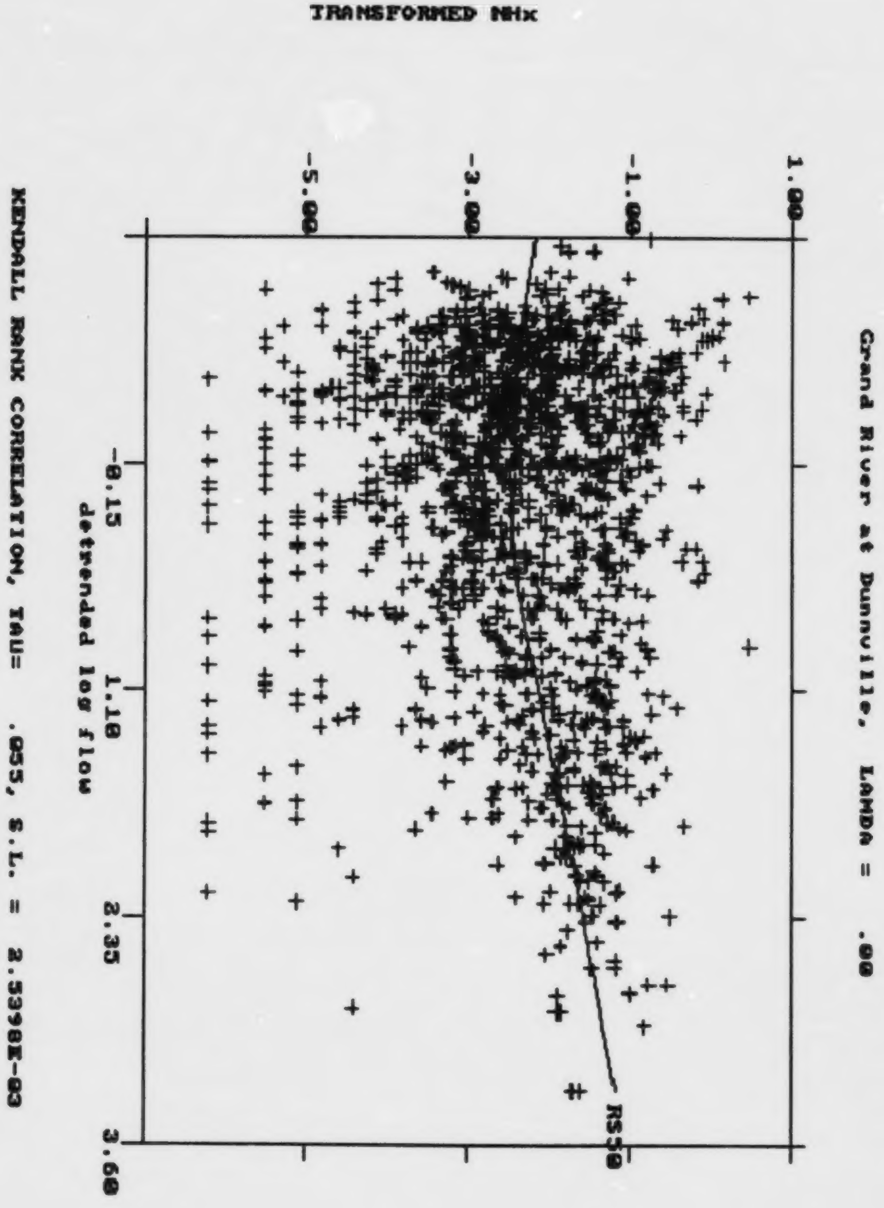
Monthly Flow-detrended NHx



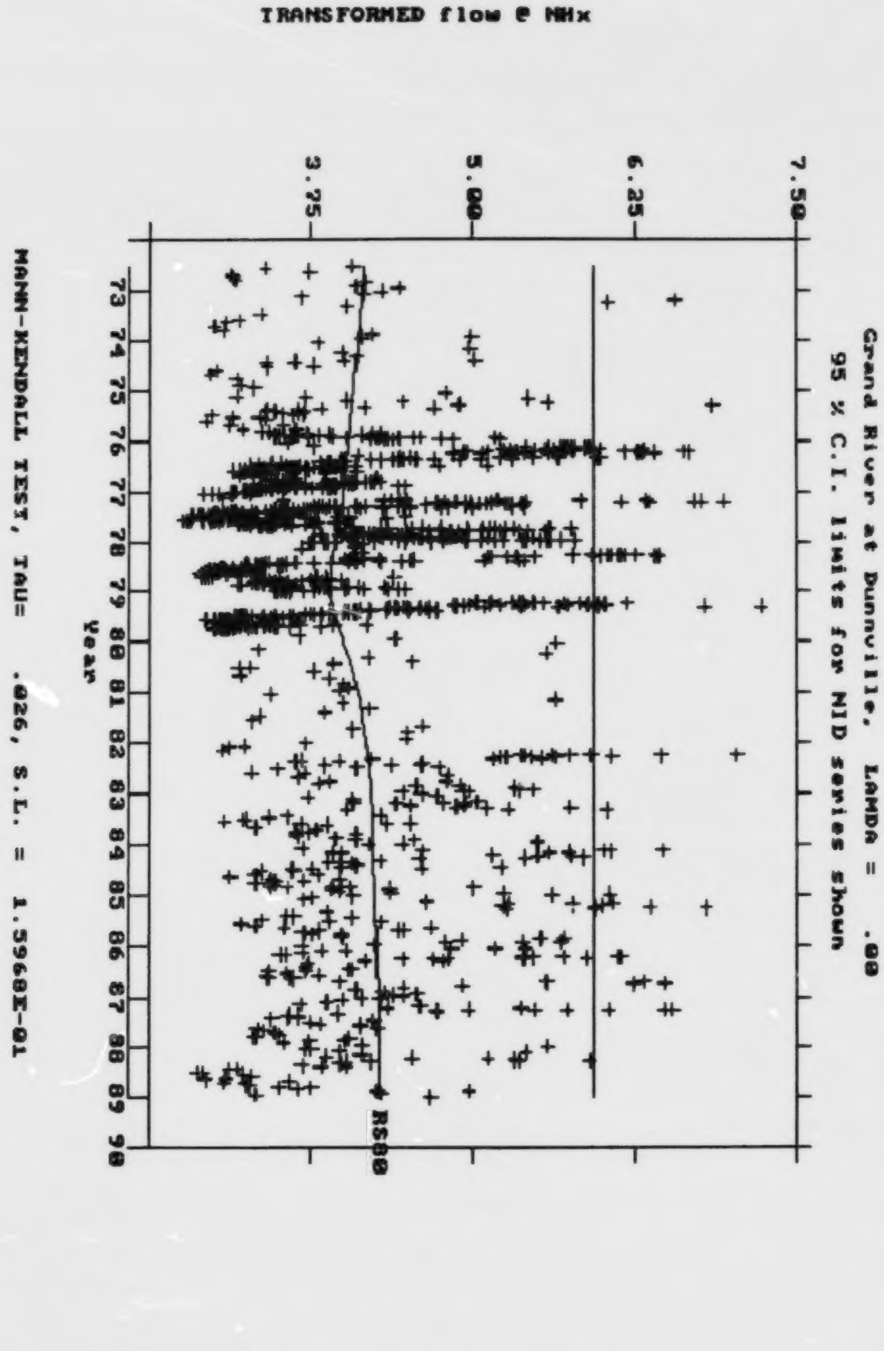
Grand.NHX.8


TRANSFORMED NHx
1.00
-1.00
-3.00
-5.00
Grand River at Dunnville, LAMDA = .00
3.75
5.00
6.25
7.50
log flow
RS50
KENDALL RANK CORRELATION, TAU= .074, S.L. = 5.4717E-05

Grand.NHX.9


TRANSFORMED NHx
Grand River at Dunnville, LAMDA = .00
1.00
-1.00
-3.00
-5.00
-0.15
1.18
2.35
3.60
detrended log flow
RS50
KENDALL RANK CORRELATION, TAU= .055, S.L. = 2.5398E-03

Grand.NHX.10


TRANSFORMED flow @ NHx
Grand River at Dunnville, LAMDA = .00
95 % C.I. limits for NID series shown
3.75
5.00
6.25
7.50
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Year
RS80
MANN-KENDALL TEST, TAU= .026, S.L. = 1.5968E-01

Grand.NHX.11

```
     Trend tests for mean monthly data


     Site: Grand River at Dunnville,

     parameter: NHx

     Basic data - not adjusted for flow


     Mann-Kendall Trend Test
           tau          Significance Level
        -.01290              7.87643E-01


     Ordinary Spearman Trend Test
           rho          Significance Level
        -.02255              7.51017E-01


     Seasonal Mann-Kendall Trend Test
     Score           Variance            Significance Level
      -37.              6589.0                   6.48520E-01


     Spearman Trend Test Partialling Out Seasonality

     Seasonal rankings:
 Season:    1  2  3  4  5  6  7  8  9 10 11 12
   Rank:   10  8  9  9  6  2  4  7  5  4  1  3

          rho           Significance Level
      -.02383                7.37388E-01
```

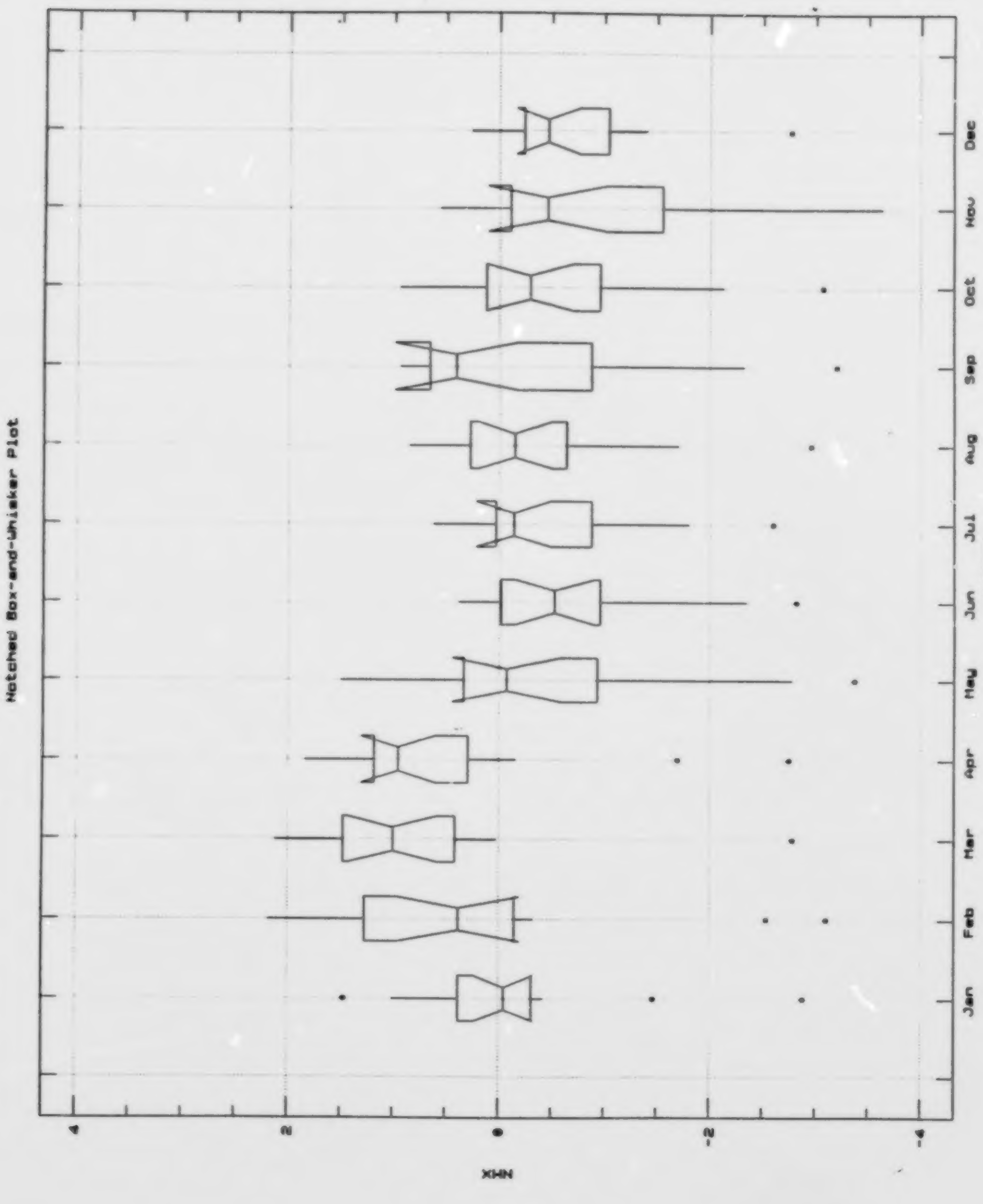
GRAND.NHX.12

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of NHX by NHXMON
--------------------------------------------------------------------------------
Level       Sample Size    Average Rank
--------------------------------------------------------------------------------
 1            16            121.750  10
 2            16            153.188  8
 3            17            165.412  9
 4            17            161.176  9
 5            16            91.8750  6
 6            17            50.2941  2
 7            16            74.8125  4
 8            17            110.647  7
 9            17            86.8235  5
10            17            78.4118  4
11            16            43.5000  1
12            17            61.2353  3
--------------------------------------------------------------------------------
Test statistic = 100.048  Significance level  = 2.22045E-16
```

Grand.NHX.13

```
     Trend tests for mean monthly data


     Site: Grand River at Dunnville,

     parameter: NHx

     Flow-adjusted Data


     Mann-Kendall Trend Test
           tau           Significance Level
        -.06649                1.69570E-01


     Ordinary Spearman Trend Test
           rho           Significance Level
        -.11089                1.24407E-01


     Seasonal Mann-Kendall Trend Test
     Score           Variance            Significance Level
      -63.              6049.0                   4.17925E-01


     Spearman Trend Test Partialling Out Seasonality

     Seasonal rankings:
 Season:    1  2  3  4  5  6  7  8  9 10 11 12
   Rank:    4  6  8  7  4  1  3  3  5  2  1  1

          rho          Significance Level
       -.10620               1.41145E-01
```

Grand.NHX.14


Notched Box-and-Whisker Plot
NHX
4
2
0
-2
-4
NHXMON
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

GRAND.NHX.15

```
----------------------------------------------------------------
Kruskal-Wallis analysis of NHX by NHXMON
----------------------------------------------------------------
Level   Rank      Sample Size        Average Rank
----------------------------------------------------------------
  1                    15              99.8000 4
  2                    15              125.133 6
  3                    16              153.375 8
  4                    16              140.188 7
  5                    15              95.2667 4
  6                    16              68.5625 1
  7                    16              82.2500 3
  8                    17              89.0588 3
  9                    17              109.176 5
 10                    17              77.7647 2
 11                    16              64.0000 1
 12                    17              64.2353 1
----------------------------------------------------------------
Test statistic = 49.5821  Significance level   = 7.44058E-7
```

Grand.NHX.16

```
     Trend tests for mean monthly data


     Site: Grand River at Dunnville,

     parameter: NHx

     Flow-adjusted Data


     Mann-Kendall Trend Test
           tau            Significance Level
        -.05354                2.68779E-01


     Ordinary Spearman Trend Test
           rho            Significance Level
        -.09188                2.02979E-01


     Seasonal Mann-Kendall Trend Test
     Score            Variance             Significance Level
      -53.               6049.0                       4.95587E-01


     Spearman Trend Test Partialling Out Seasonality

     Seasonal rankings:
 Season:    1  2  3  4  5  6  7  8  9 10 11 12
   Rank:    6  7  9  8  5  2  4  4  6  3  1  1

         rho            Significance Level
      -.08894                2.17808E-01
```

GRAND.NHX.17

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of NHX by NHXMON
--------------------------------------------------------------------------------
Level         Sample Size     Average Rank
--------------------------------------------------------------------------------
  1              15          106.333  6
  2              15          121.800  7
  3              16          155.875  9
  4              16          145.000  8
  5              15          96.4000  5
  6              16          68.5625  2
  7              16          81.6875  4
  8              17          86.1176  4
  9              17          108.118  6
 10               17          75.4706  3
 11               16          61.1250  1
 12               17          63.0588  1
--------------------------------------------------------------------------------
Test statistic = 55.0365  Significance level  = 7.63156E-8
```

Grand.TKN

Grand River at Dunnville

total Kjeldahl nitrogen

Table of Contents: Grand.TKN

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs TKN

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(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box-and-whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Summary and Conclusions

Grand River - TKN

Data Transformation: logarithmic

Seasonality: very strong

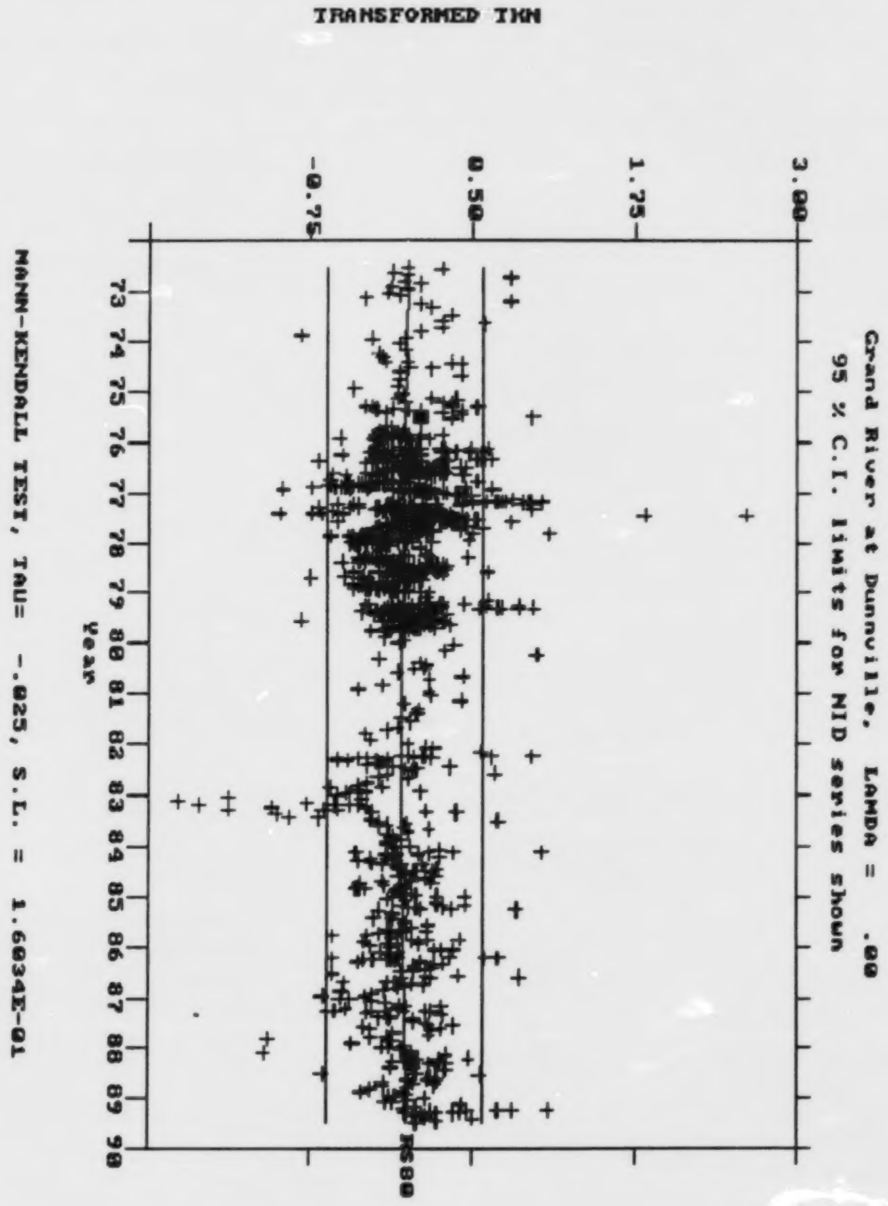
Flow-Concentration Relationship: possible U-shaped relationship

Outliers: pattern of low outliers in 1983

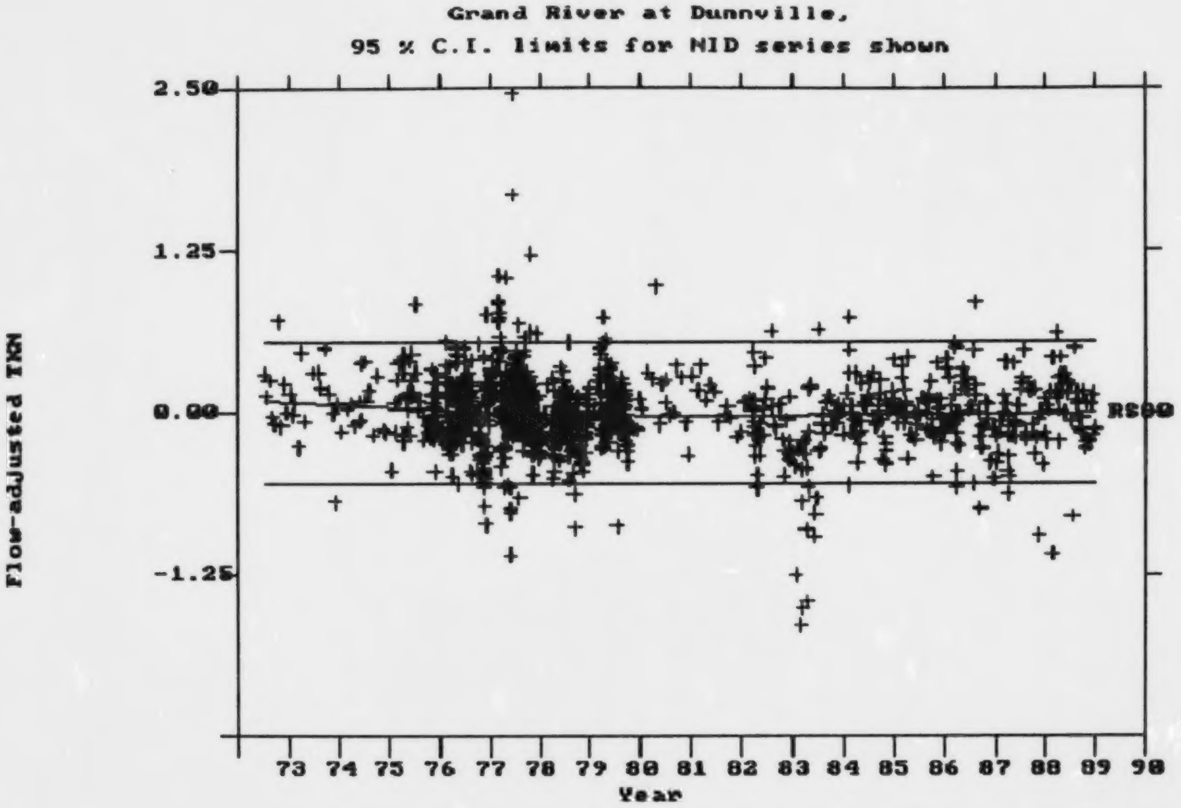
Trend: Significant and continual downward trend in both the flow-adjusted and detrended-flow-adjusted data over the period 1972-1989. No trend in unadjusted (original) data.

Other:

Grand.TKN.2


Grand River at Dunnville. LAMDA = .00
95 % C.I. limits for NID series shown
TRANSFORMED TKN
3.00
1.75
0.50
-0.75
73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
Year
RS80
MANN-KENDALL TEST, TAU= -.025, S.L. = 1.6034E-01

Grand.TKN.3



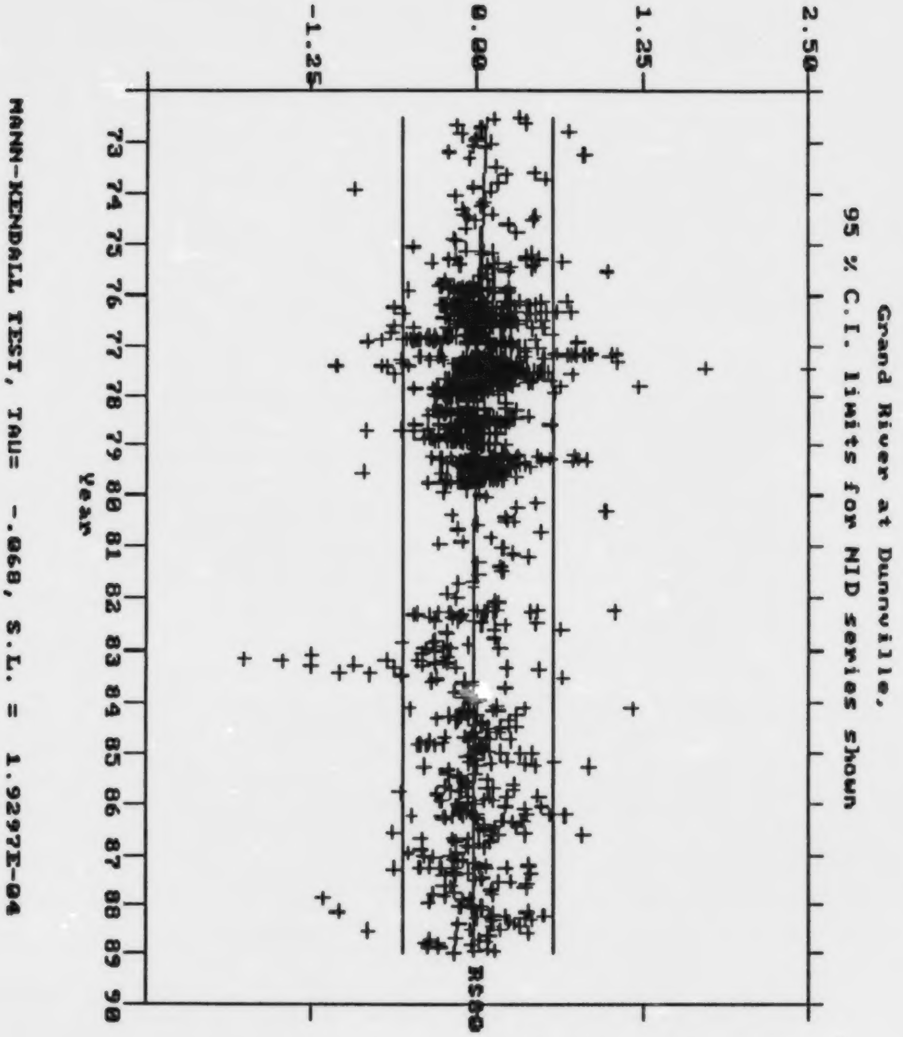
Grand River at Dunnville,
95 % C.I. limits for NID series shown

MANN-KENDALL TEST, TAU= -.062, S.L. = 5.8155E-04

Grand.TKN.4

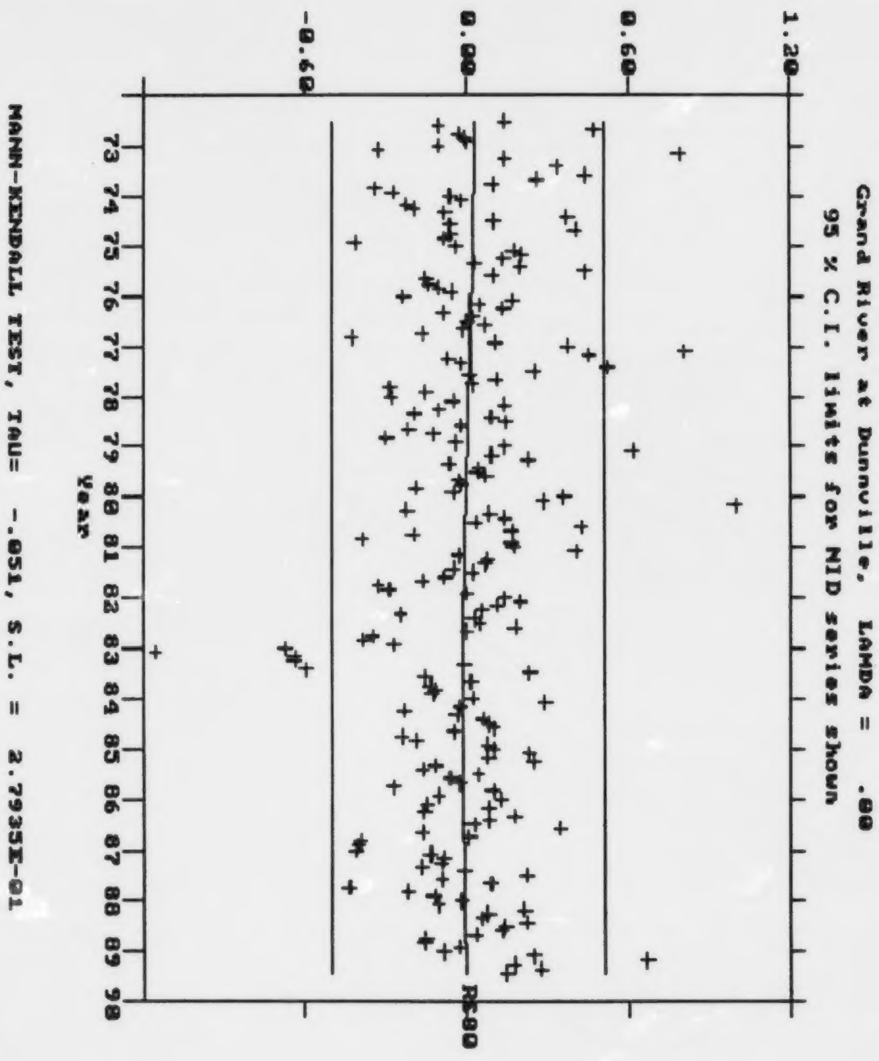
Detrended

Flow-adjusted TKN



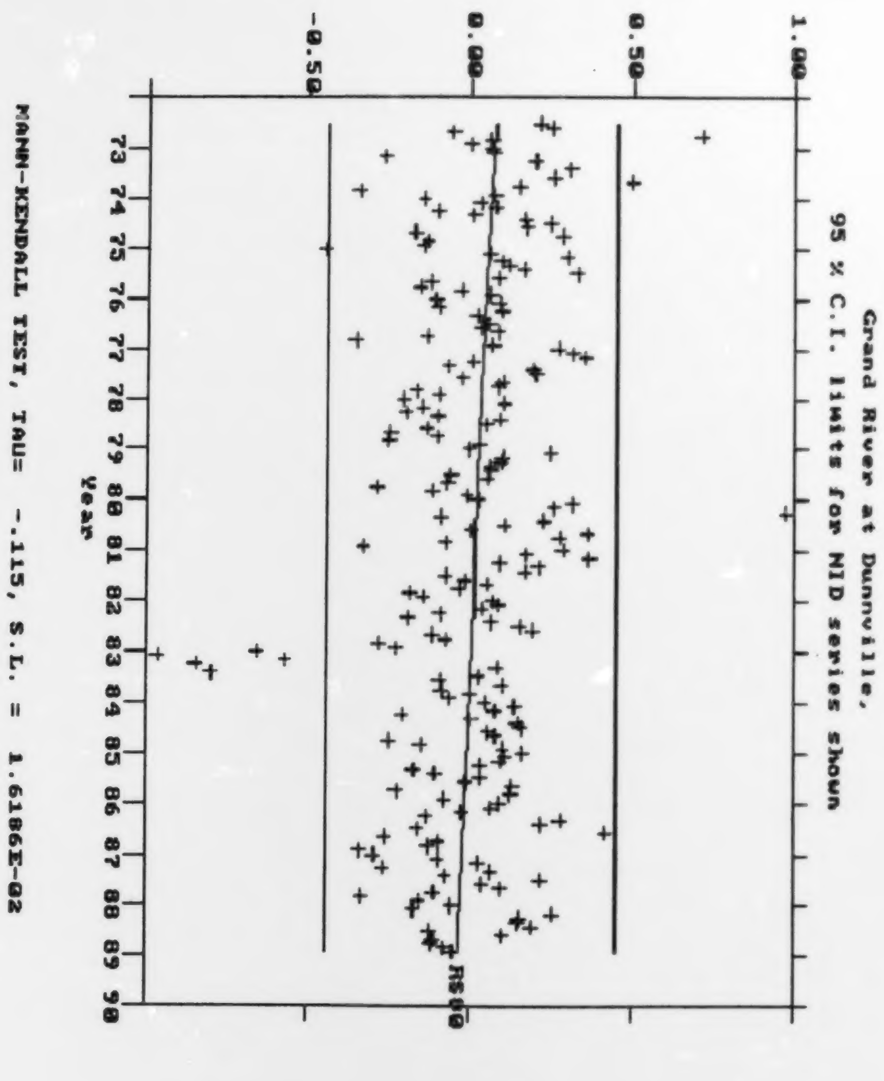
Grand.TKN.5

Monthly TKN

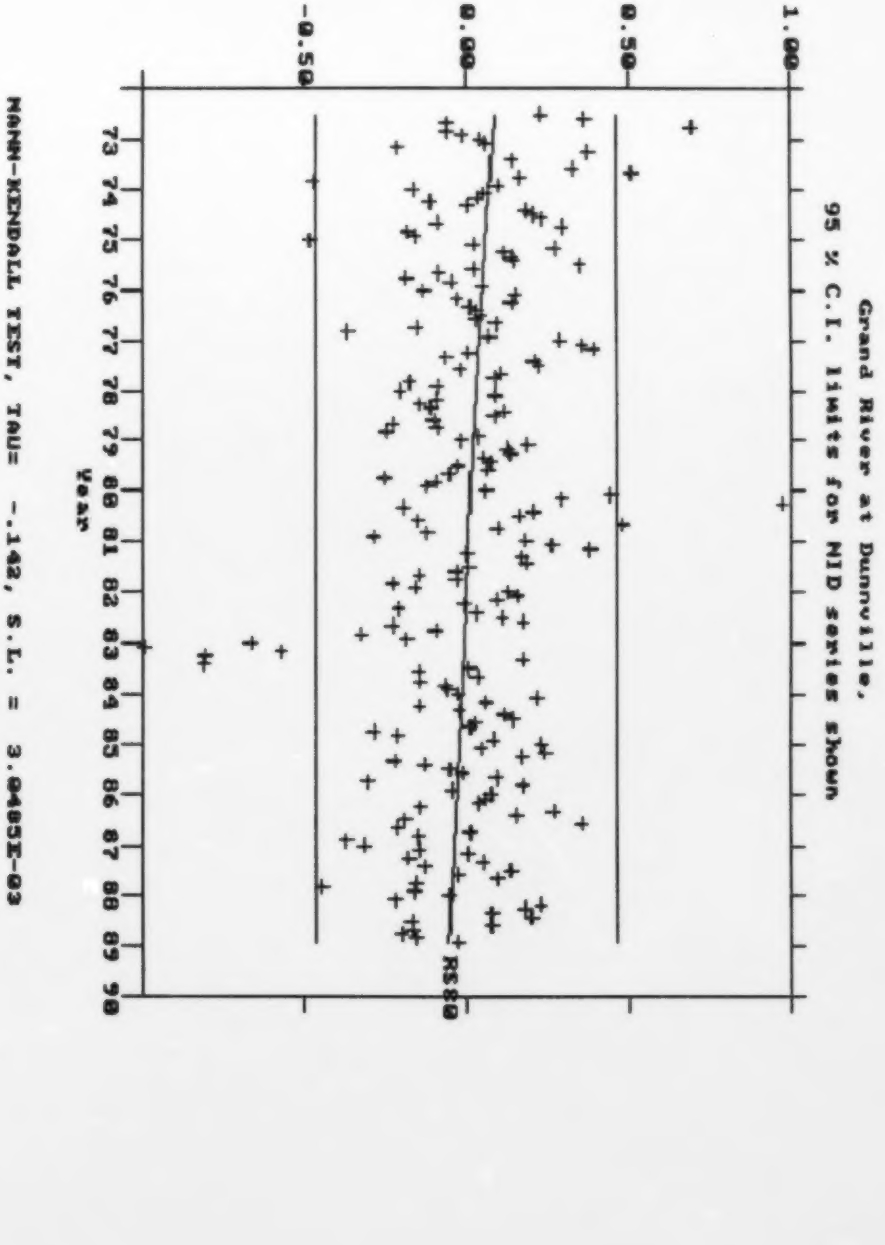


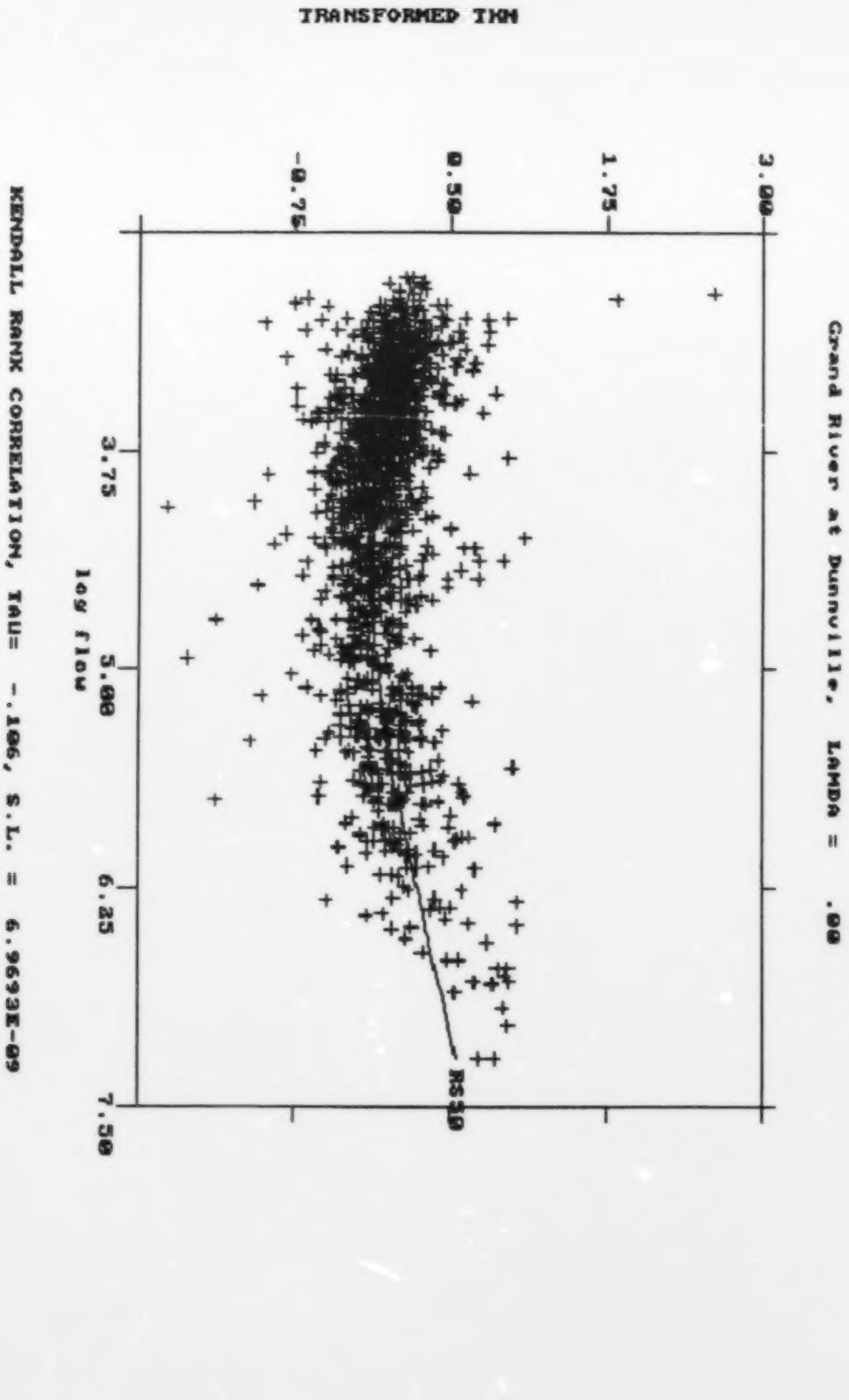
Grand.TKN.6

Monthly Flow adjusted TKN

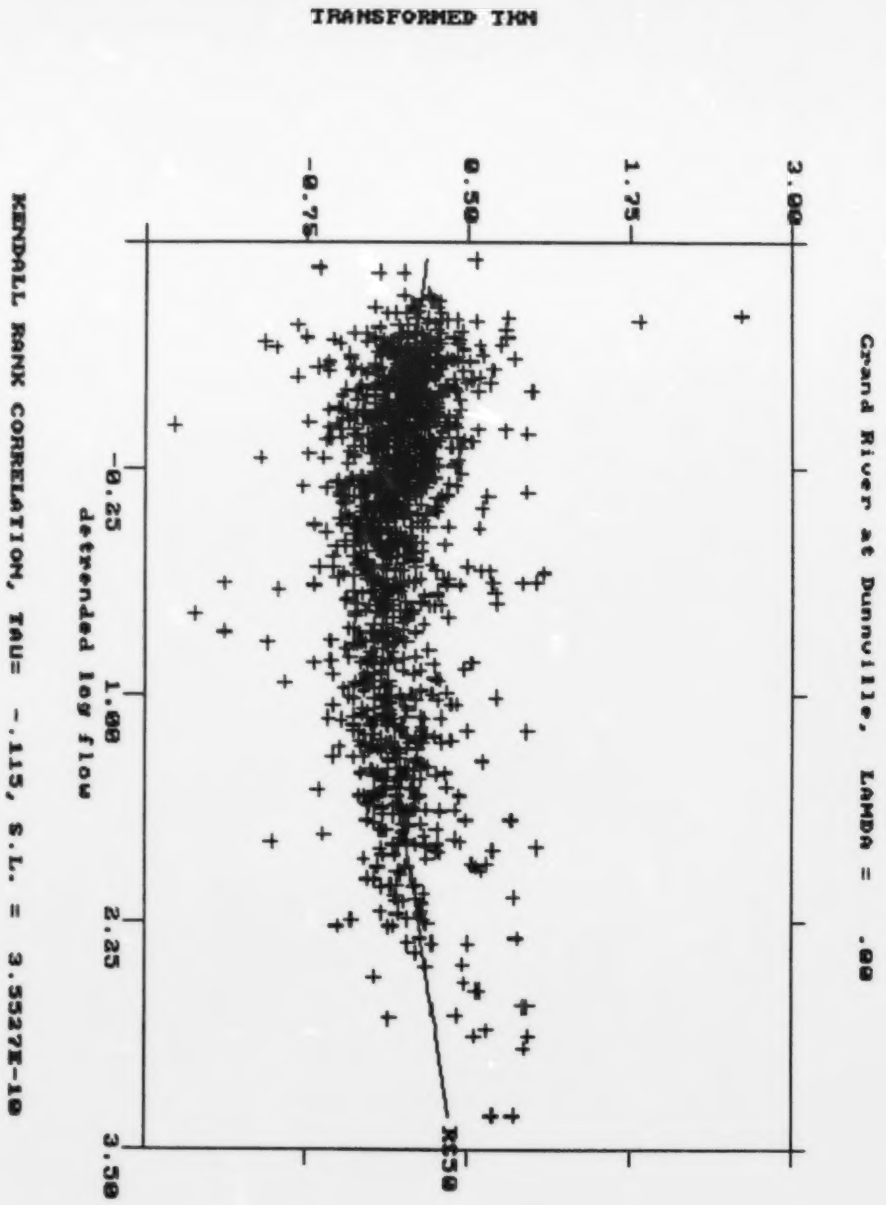


Monthly Flow-detrended TKN

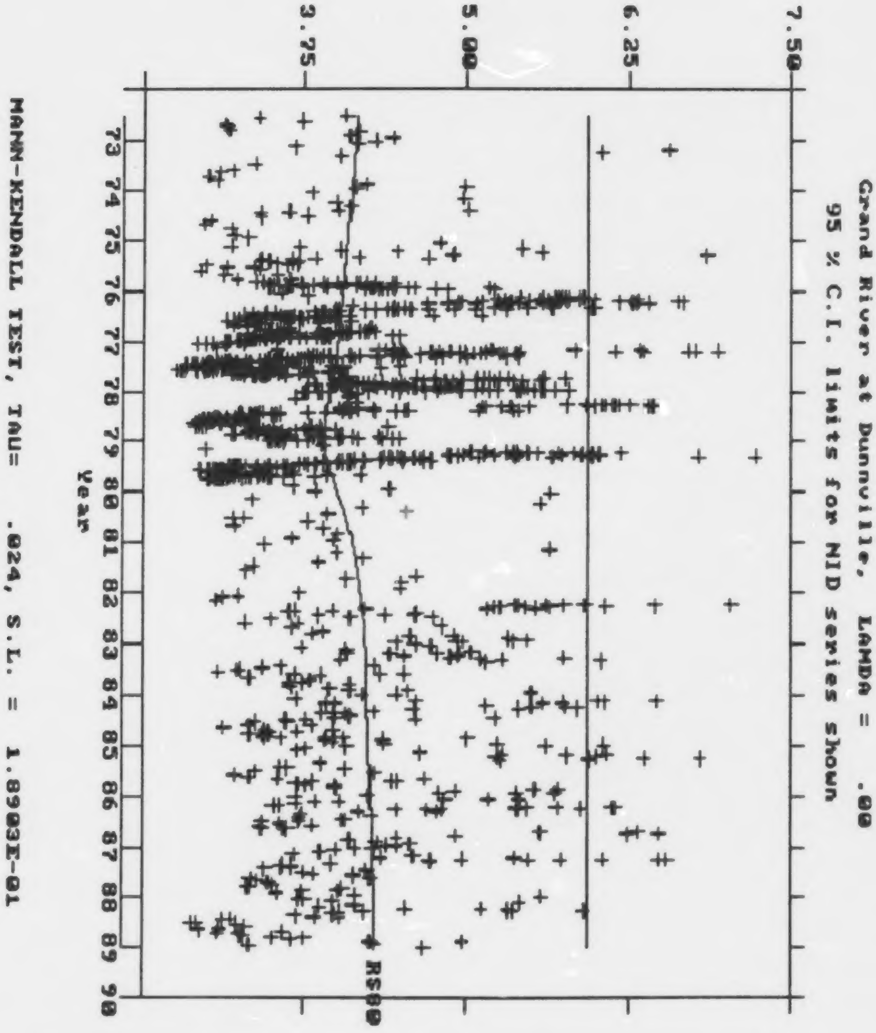



TRANSFORMED TKN
-0.75
0.50
1.75
3.00
3.75
5.00
6.25
7.50
log flow
RS30
Grand River at Dunnville, LAMDA = .00
KENDALL RANK CORRELATION, TAU= -.106, S.L. = 6.9693E-09

Grand.TKN.9


TRANSFORMED TKN
Grand River at Dunnville, LAMDA = .00
3.00
1.75
0.50
-0.75
-0.25
1.00
2.25
3.50
detrended log flow
KENDALL RANK CORRELATION, TAU= -.115, S.L. = 3.5527E-10
X=50

TRANSFORMED flow @ TKN



```
    Trend tests for mean monthly data


    Site: Grand River at Dunnville,

    parameter: TKN

    Basic data - not adjusted for flow


    Mann-Kendall Trend Test
          tau             Significance Level
       -.05132                 2.79350E-01


    Ordinary Spearman Trend Test
          rho             Significance Level
       -.08099                 2.50884E-01


    Seasonal Mann-Kendall Trend Test
    Score            Variance             Significance Level
    -137.               6875.0                     9.84771E-02


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    9  9  8  7  6  5  3  1  2  4  6  8

        rho           Significance Level
     -.08347                 2.36660E-01
```

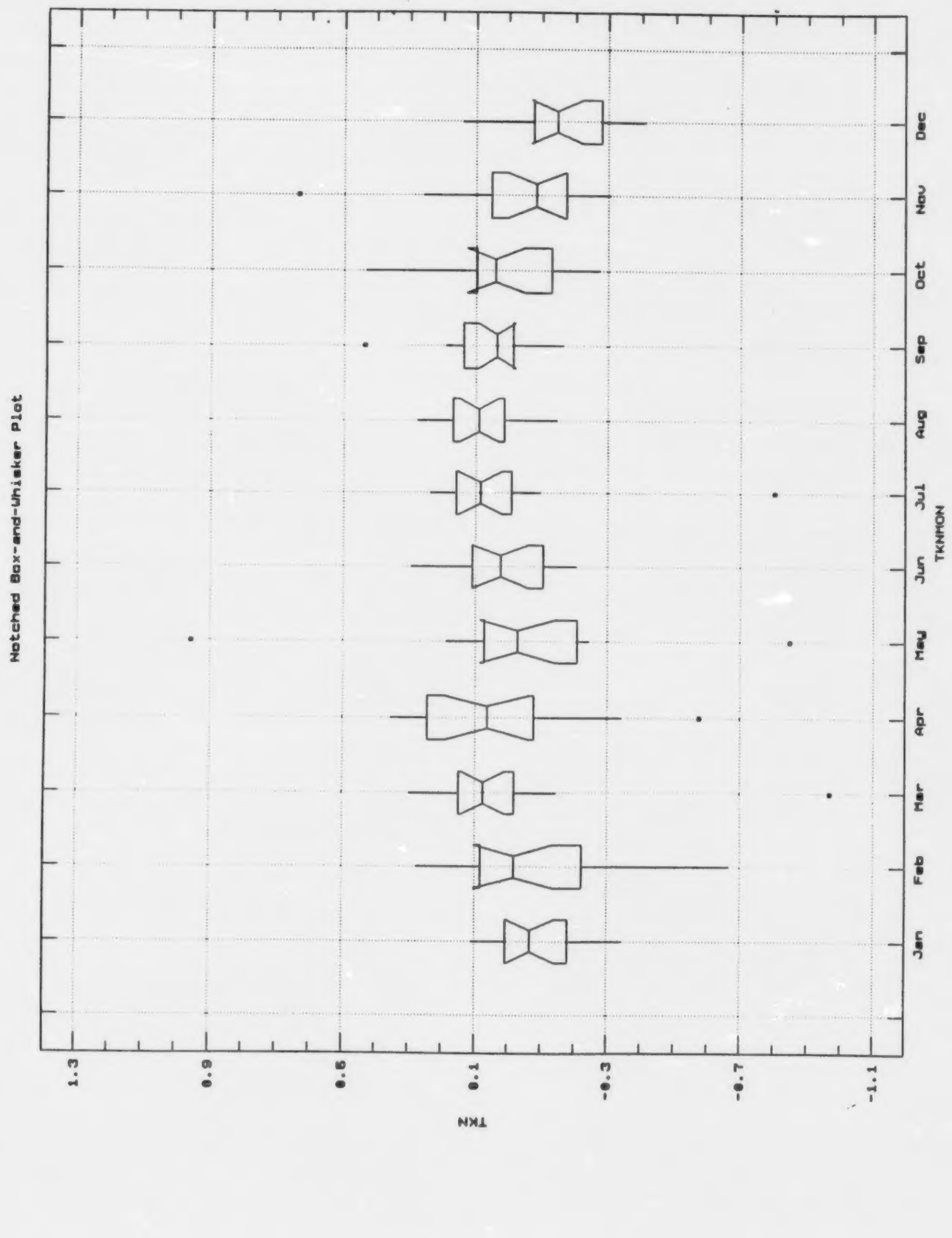
GRAND.TKN:12

```
---------------------------------------------------------------------------
Kruskal-Wallis analysis of TKN by TKNMON
---------------------------------------------------------------------------
Level          Sample Size    Average Rank
---------------------------------------------------------------------------
  1               17            163.882  9
  2               17            164.059  9
  3               17            149.176  8
  4               17            127.706  7
  5               16            101.438  6
  6               17            83.2353  5
  7               16            47.8125  3
  8               17            31.6471  1
  9               17            39.0000  2
 10                17            61.6471  4
 11                17            98.4706  6
 12                17            146.765  8
---------------------------------------------------------------------------
Test statistic = 130.558  Significance level  = 0
```

Grand.TKN.13

```
    Trend tests for mean monthly data


    Site: Grand River at Dunnville,

    parameter: TKN

    Flow-adjusted Data


    Mann-Kendall Trend Test
          tau           Significance Level
       -.11533                1.61858E-02


    Ordinary Spearman Trend Test
          rho           Significance Level
       -.17220                1.61864E-02


    Seasonal Mann-Kendall Trend Test
    Score          Variance            Significance Level
    -187.             6315.0                      1.86137E-02


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    2  3  6  6  3  5  7  7  6  4  3  1

         rho          Significance Level
     -.17032               1.73889E-02
```

Grand.TKN.14


Notched Box-and-Whisker Plot
TKN
1.3
0.9
0.5
0.1
-0.3
-0.7
-1.1
TKNMON
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

GRAND.TKN.15

```
--------------------------------------------------------------------
Kruskal-Wallis analysis of TKN by TKNMON
--------------------------------------------------------------------
Level              Sample Size     Average Rank
--------------------------------------------------------------------
  1                     16             67.3750  2
  2                     16             87.3125  3
  3                     16             120.563  6
  4                     16             116.313  6
  5                     15             85.8000  3
  6                     16             105.625  5
  7                     16             124.188  7
  8                     17             127.471  7
  9                     17             118.118  6
 10                     17             97.5294  4
 11                     17             82.0588  3
 12                     17             49.9412  1
--------------------------------------------------------------------
Test statistic = 34.0818  Significance level   = 3.50723E-4
```

```
     Trend tests for mean monthly data


     Site: Grand River at Dunnville,

     parameter: TKN

     Flow-adjusted Data


     Mann-Kendall Trend Test
           tau           Significance Level
        -.14192                3.04854E-03


     Ordinary Spearman Trend Test
           rho           Significance Level
        -.21022                3.32979E-03


     Seasonal Mann-Kendall Trend Test
     Score           Variance          Significance Level
     -245.              6315.0                     2.04896E-03


     Spearman Trend Test Partialling Out Seasonality

     Seasonal rankings:
 Season:    1  2  3  4  5  6  7  8  9 10 11 12
   Rank:    2  4  8  8  5  6  8  8  7  4  3  1

          rho          Significance Level
       -.21928               2.19775E-03
```

GRAND.TKN.17

```
------------------------------------------------------------------------
Kruskal-Wallis analysis of TKN by TKNMON
------------------------------------------------------------------------
Level        Sample Size    Average Rank
------------------------------------------------------------------------
  1            16          68.6875   2
  2            16          86.7500   4
  3            16          121.813   8
  4            16          124.063   8
  5            15          97.6000   5
  6            16          105.750   6
  7            16          124.188   8
  8            17          124.235   8
  9            17          114.941   7
 10             17          91.2353  4
 11             17          79.9412  3
 12             17          45.0588  1
------------------------------------------------------------------------
Test statistic = 36.7189  Significance level  = 1.28416E-4
```

Grand.NOx

Grand River at Dunnville

Total Nitrates

Table of Contents: Grand.NOX

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs NOX

(9) Scatter and smooth of detrended-flow vs NOX

(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box-and-whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Summary and Conclusions

Grand River - NOx

Data Transformation: logarithmic

Seasonality: very strong

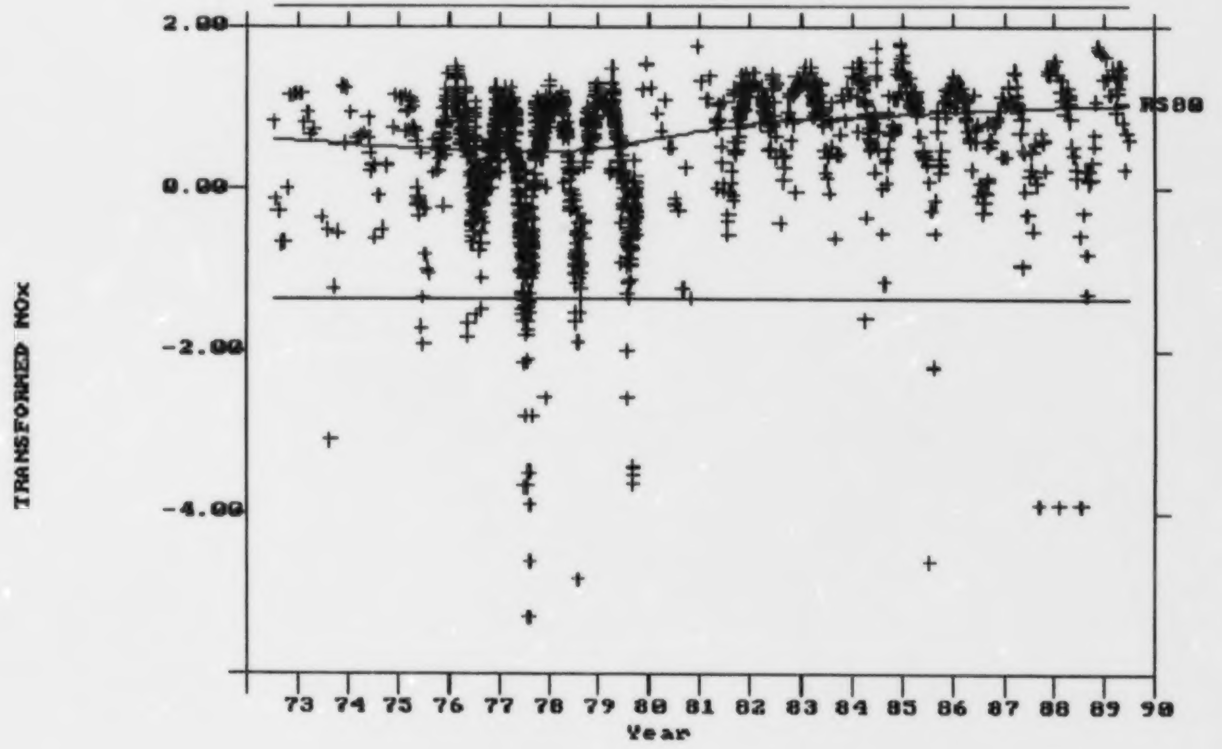
Flow-Concentration Relationship: Positive asymptotic relationship

Outliers: none apparent

Trend: Highly significant positive trend in original data and in the detrended-flow-adjusted data. Regular flow-adjusted data does not show as strong a trend. The upward trend is most signficant from 1972-1981 and relatively constant from 1982-1989.

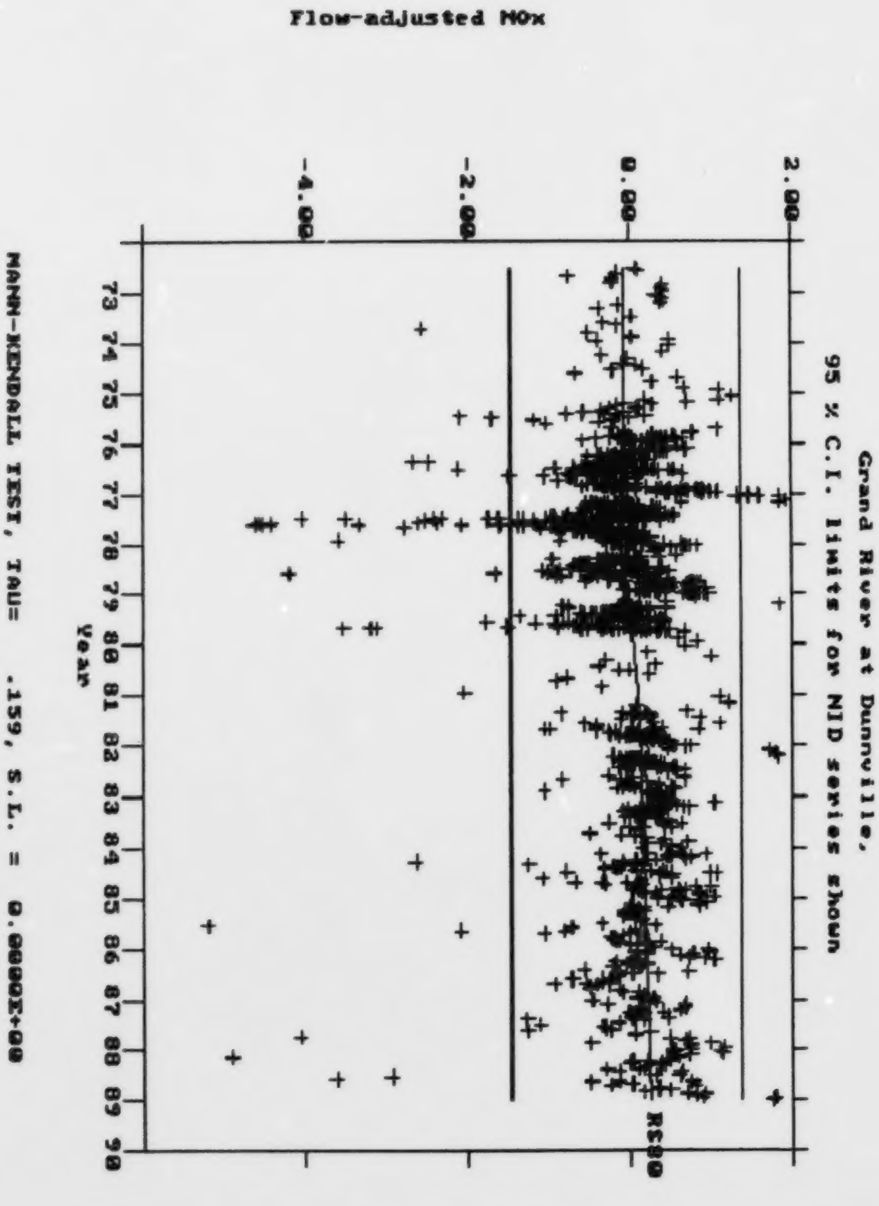
Other:

Grand.NOX.2


Grand River at Dunnville, LAMDA = .00
95 % C.I. limits for NID series shown

MANN-KENDALL TEST, TAU= .189, S.L. = 0.0000E+00

Grand.NOX.3



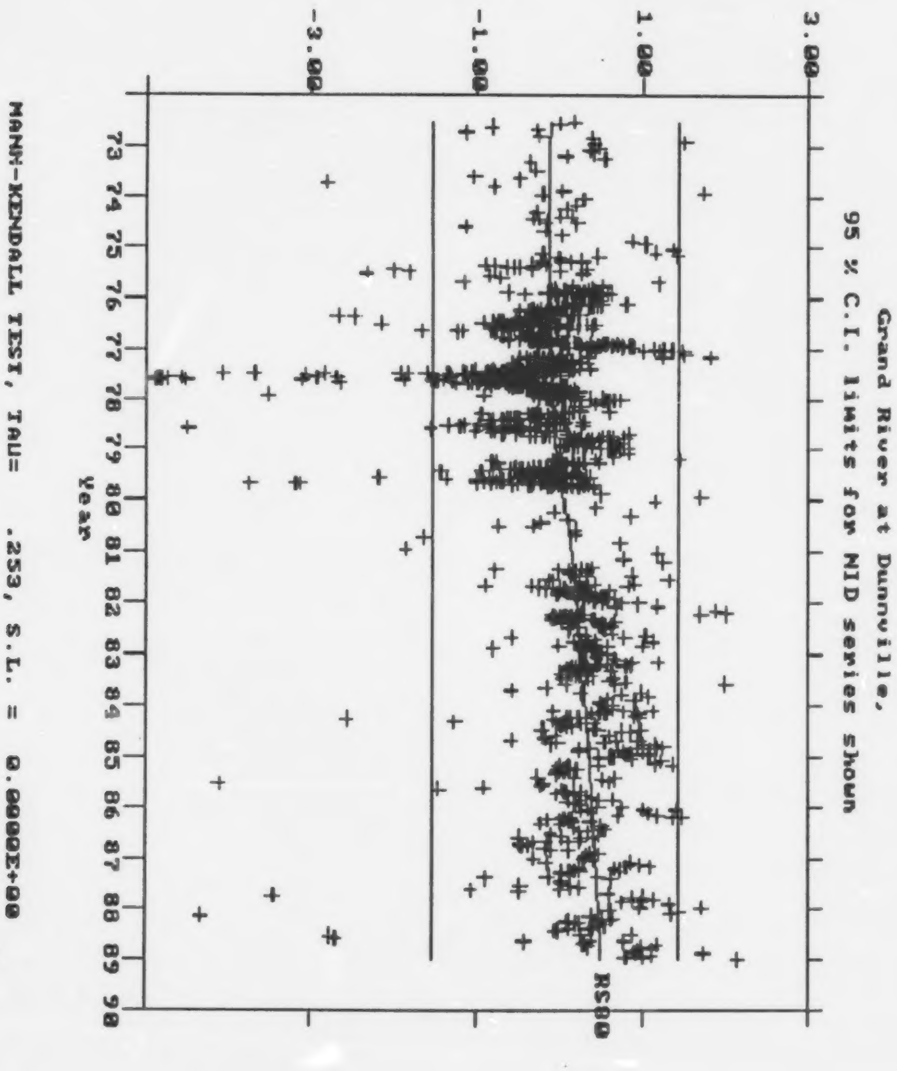
Grand River at Dunnville,
95 % C.I. limits for NID series shown

MANN-KENDALL TEST, TAU= .159, S.L. = 0.0000E+00

Grand.NOX.4

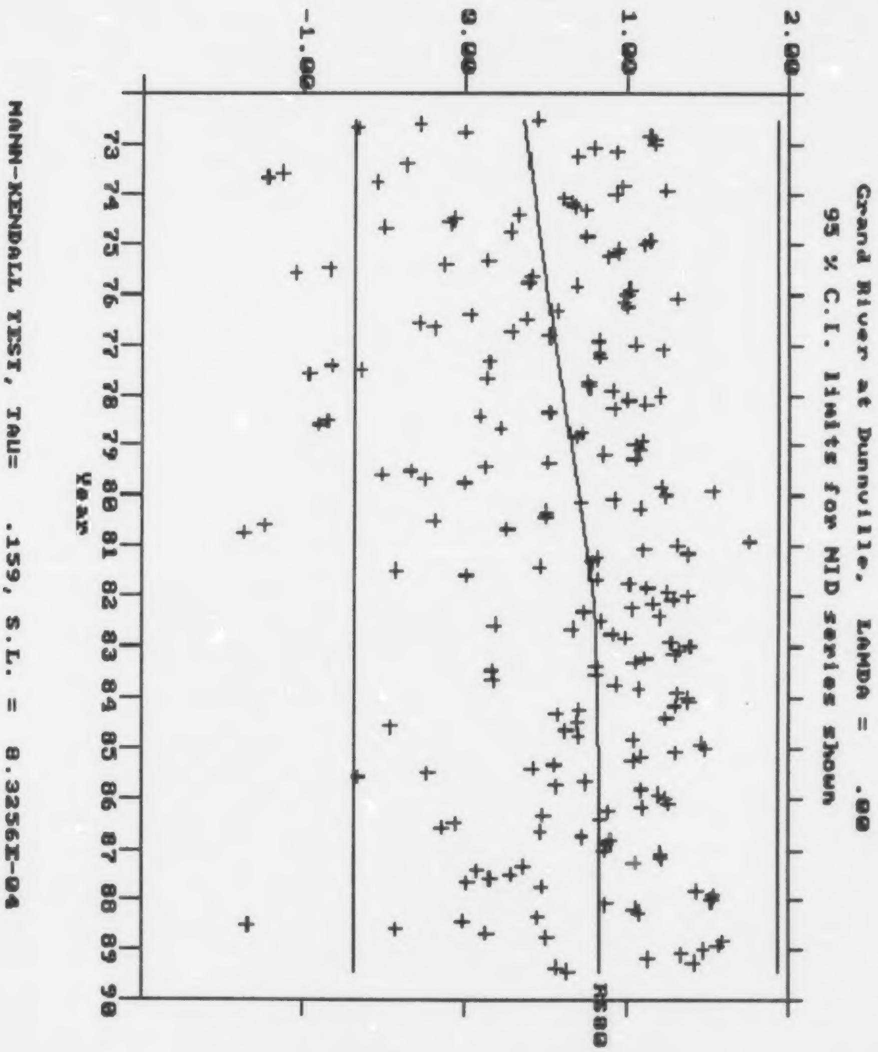
Detrended

Flow-adjusted NOx



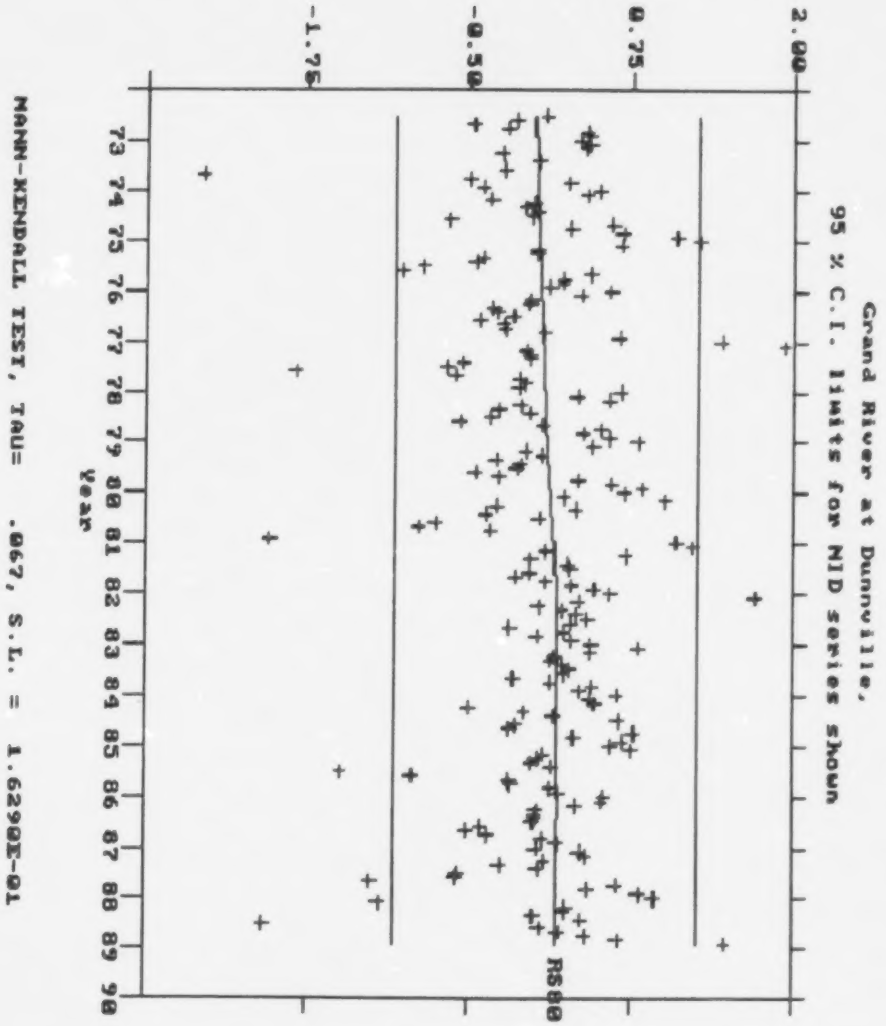
Grand.NOX.5

Monthly NOx



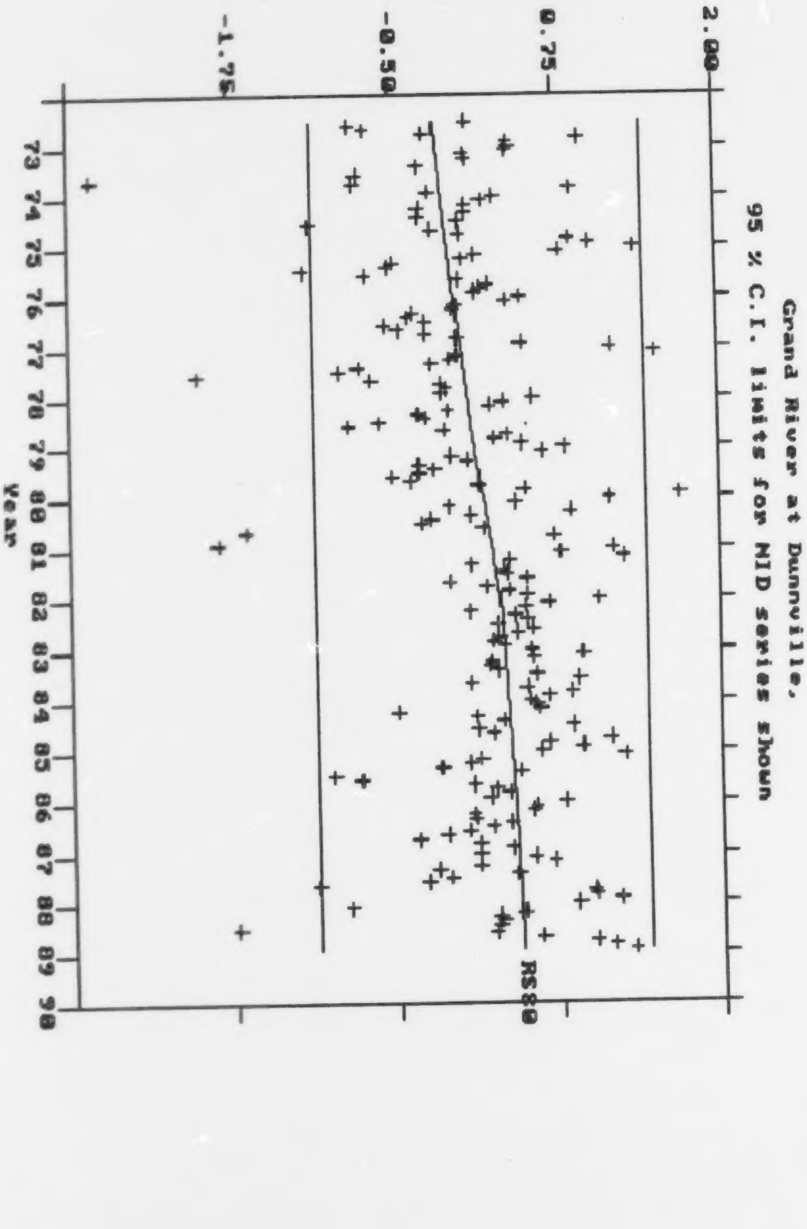
Grand.NOX.6

Monthly Flow adjusted NOx



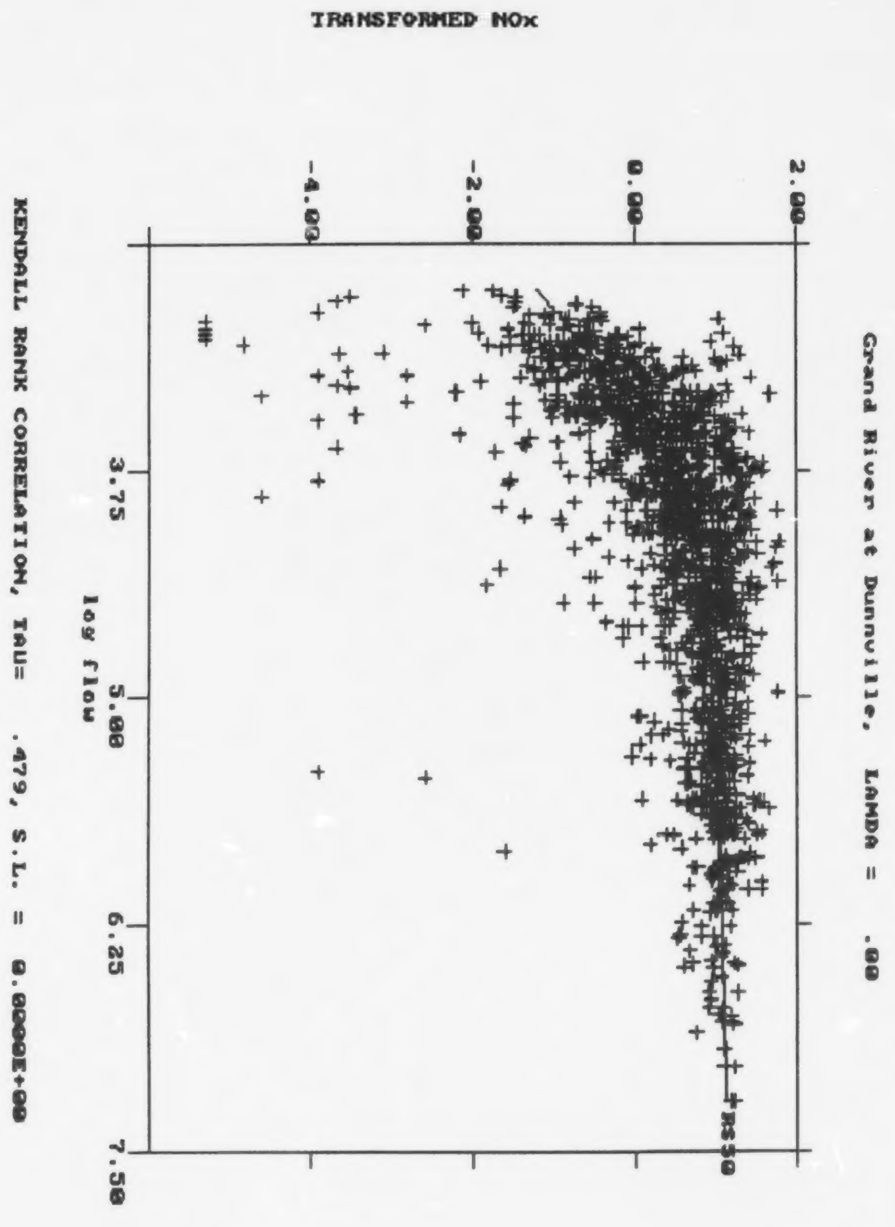
Grand.NOX.7

Monthly Flow-detrended NOx

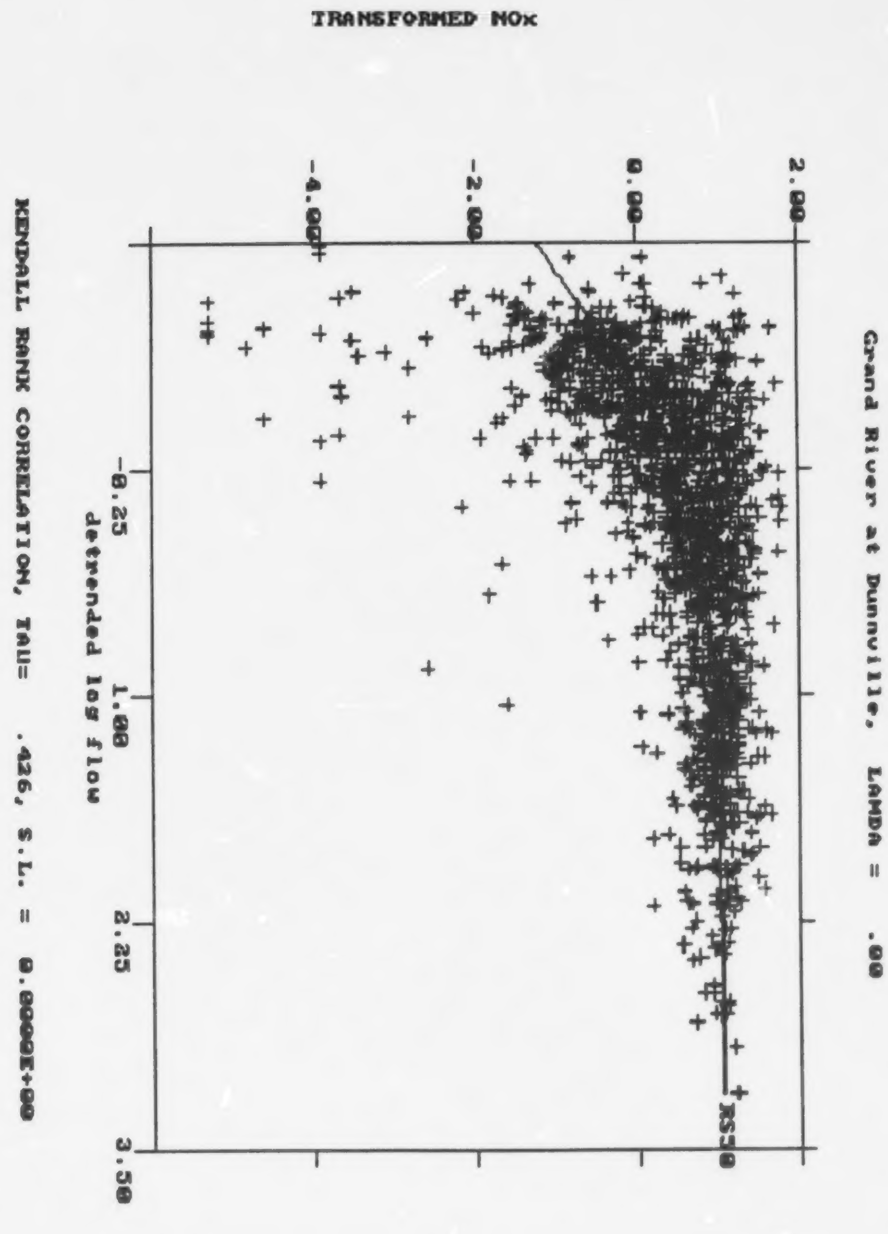


MANN-KENDALL TEST, TAU= .282, S.L. = 2.4796E-05

Grand.NOX.8

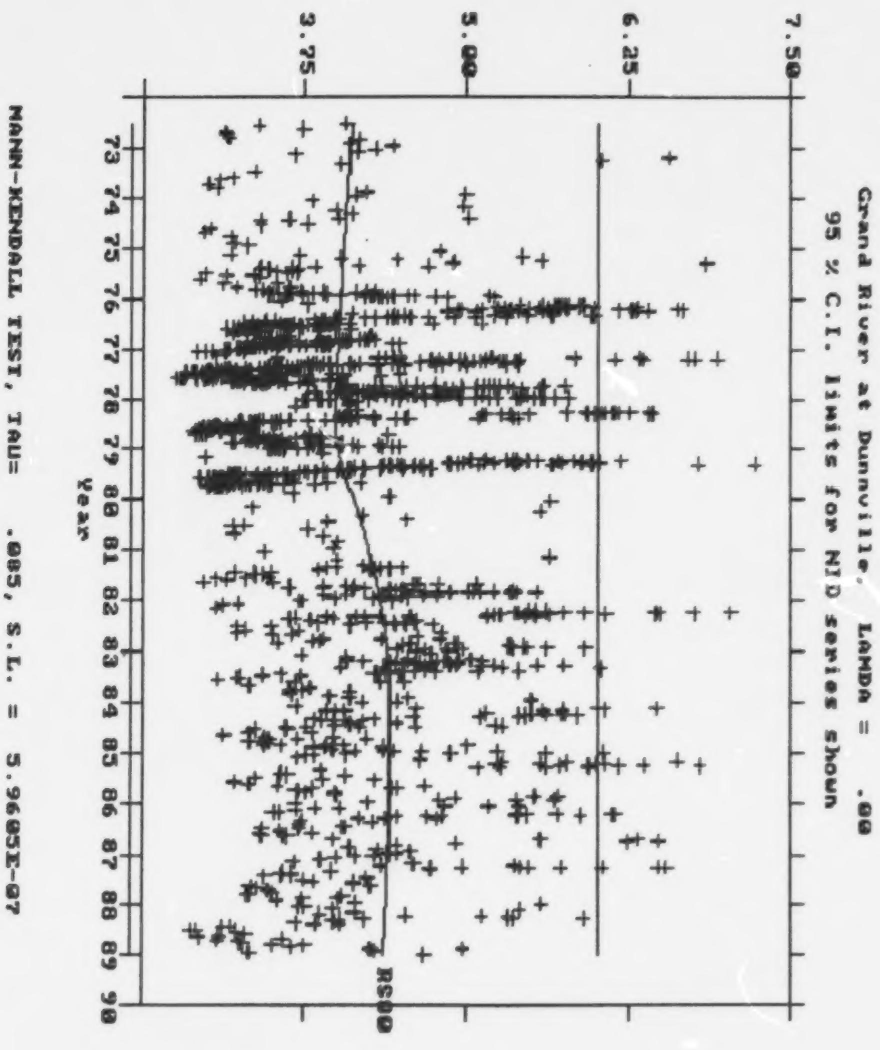

Grand River at Dunnville, LAMDA = .00
TRANSFORMED NOx
2.00
0.00
-2.00
-4.00
3.75
5.00
6.25
7.50
log flow
RS50
KENDALL RANK CORRELATION, TAU= .479, S.L. = 0.0000E+00

Grand.NOX.9


Grand River at Dunnville, LAMDA = .00
TRANSFORMED NOx
2.00
0.00
-2.00
-4.00
-0.25
1.00
2.25
3.50
detrended log flow
RS38
KENDALL RANK CORRELATION, TAU= .426, S.L. = 0.0000E+00

Grand.NOX.10

TRANSFORMED flow @ NOx



Grand.NOX.11

```
    Trend tests for mean monthly data


    Site: Grand River at Dunnville,

    parameter: NOx

    Basic data - not adjusted for flow


    Mann-Kendall Trend Test
          tau          Significance Level
        .15858               8.32558E-04


    Ordinary Spearman Trend Test
          rho          Significance Level
        .23762               7.77960E-04


    Seasonal Mann-Kendall Trend Test
    Score          Variance          Significance Level
     488.             6782.0                0.00000E+00


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    9 10  8  7  6  5  4  2  1  3  5  6

        rho          Significance Level
      .29674              2.70605E-05
```

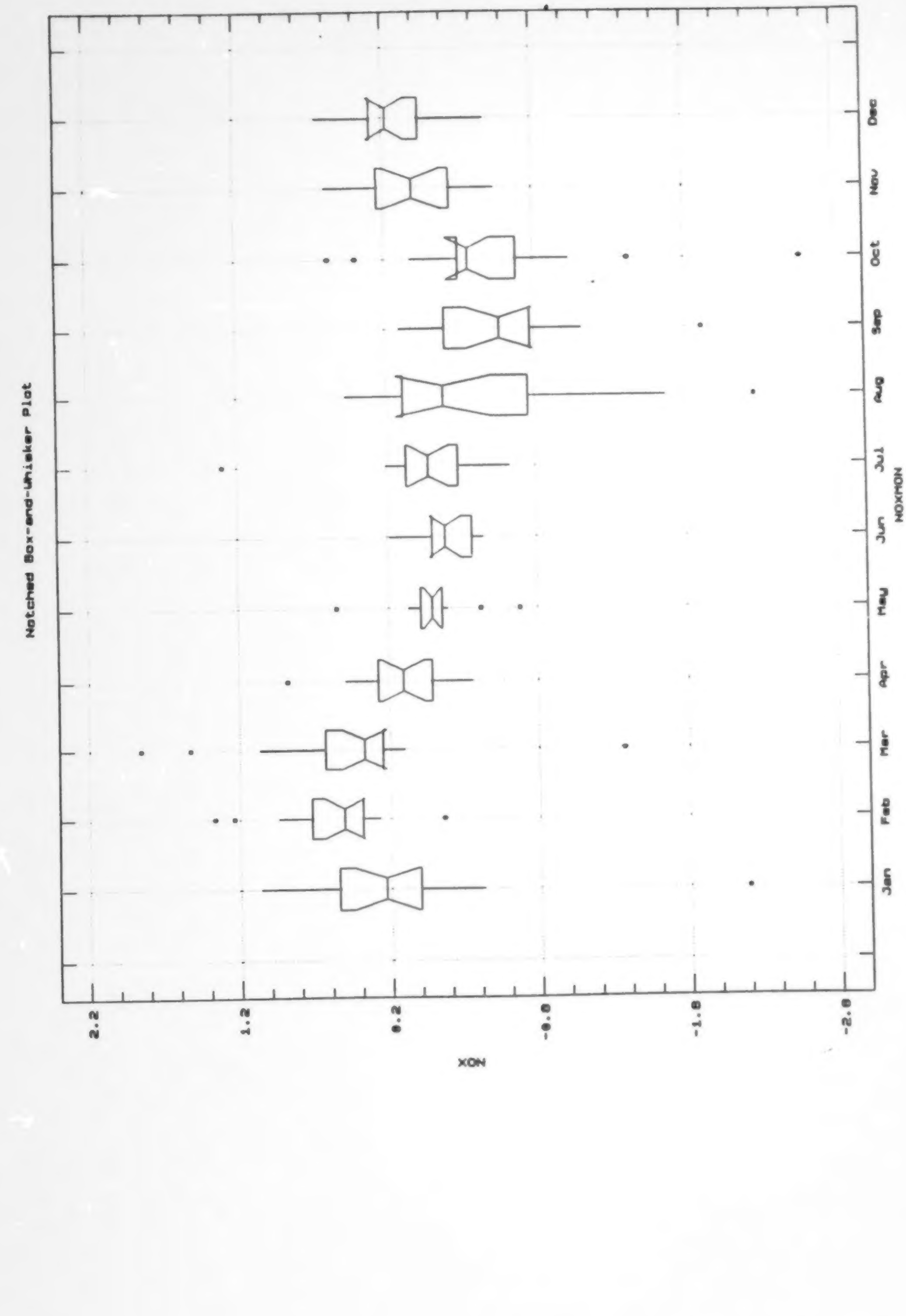
GRAND.NOX.12

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of NOX by NOXMON
--------------------------------------------------------------------------------
Level          Sample Size    Average Rank
--------------------------------------------------------------------------------
  1               17          167.588  9
  2               17          170.412 10
  3               17          151.118  8
  4               17          139.882  7
  5               16          126.188  6
  6               17          78.6471  5
  7               16          65.3125  4
  8               17          37.8824  2
  9               17          23.9412  1
 10               17           47.8235 3
 11               16           74.6250 5
 12               17           126.412 6
--------------------------------------------------------------------------------
Test statistic = 148.828  Significance level  = 0
```

Grand.NOX.13

```
    Trend tests for mean monthly data


    Site: Grand River at Dunnville,

    parameter: NOx

    Flow-adjusted Data


    Mann-Kendall Trend Test
          tau          Significance Level
       .06730               1.62898E-01


    Ordinary Spearman Trend Test
          rho          Significance Level
       .10544               1.41941E-01


    Seasonal Mann-Kendall Trend Test
    Score          Variance          Significance Level
     181.             6219.0                  2.17223E-02


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:     1  2  3  4  5  6  7  8  9 10 11 12
  Rank:     9 11 10  7  5  3  5  4  1  2  6  8

         rho          Significance Level
      .14602               4.19632E-02
```

Grand.NOX.14


Notched Box-and-Whisker Plot
NOX
2.2
1.2
0.2
-0.8
-1.8
-2.8
NOXMON
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

GRAND.NOX.15

```
------------------------------------------------------------
Kruskal-Wallis analysis of NOX by NOXMON
------------------------------------------------------------
Level               Sample Size      Average Rank
------------------------------------------------------------
  1                      16             128.313 9
  2                      16             164.500 11
  3                      16             151.250 10
  4                      16             115.938 7
  5                      15             83.8000 5
  6                      16             65.3125 3
  7                      16             85.6875 5
  8                      17             70.3529 4
  9                      17             41.2353 1
 10                      17             53.9412 2
 11                      16             99.8125 6
 12                      17             121.529 8
------------------------------------------------------------
Test statistic = 84.382  Significance level  = 2.08389E-13
```

```
     Trend tests for mean monthly data


     Site: Grand River at Dunnville,

     parameter: NOx

     Flow-adjusted Data


     Mann-Kendall Trend Test
           tau          Significance Level
         .20180                2.47955E-05


     Ordinary Spearman Trend Test
           rho          Significance Level
         .30309                2.43187E-05


     Seasonal Mann-Kendall Trend Test
     Score          Variance          Significance Level
      435.             6219.0                 0.00000E+00


     Spearman Trend Test Partialling Out Seasonality

     Seasonal rankings:
 Season:    1  2  3  4  5  6  7  8  9 10 11 12
   Rank:    6  9  8  5  3  2  3  2  1  1  4  7

          rho          Significance Level
        .35095               1.07288E-06
```

GRAND.NOX.17

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of NOX by NOXMON
--------------------------------------------------------------------------------
Level          Sample Size     Average Rank
--------------------------------------------------------------------------------
 1               16           127.313   6
 2               16           158.188   9
 3               16           147.688   8
 4               16           115.938   5
 5               15           79.4667    3
 6               16           66.0000    2
 7               16           78.1250    3
 8               17           65.2353    2
 9               17           51.5882    1
10                17           50.5294   1
11                16           103.813   4
12                17           136.471   7
--------------------------------------------------------------------------------
Test statistic = 82.6035  Significance level  = 4.61964E-13
```

Grand.FRP

Grand River at Dunnville

Filtered Reactive Phosphorus

Table of Contents: Grand.FRP

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs FRP

(9) Scatter and smooth of detrended-flow vs FRP

(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box-and-whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Summary and Conclusions

Grand River - FRP

Data Transformation: logarithmic

Seasonality: very strong

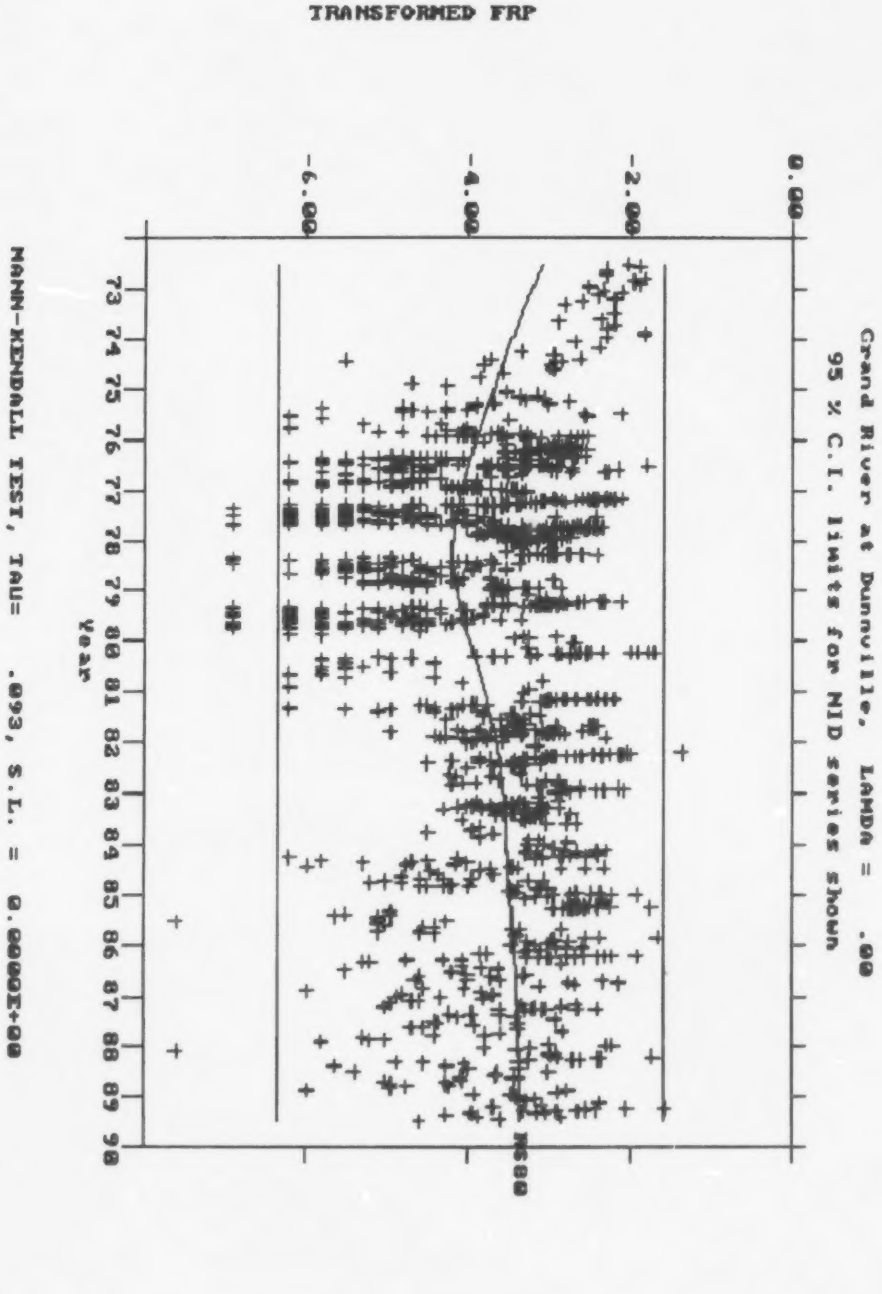
Flow-Concentration Relationship: positive, curved

Outliers: none apparent

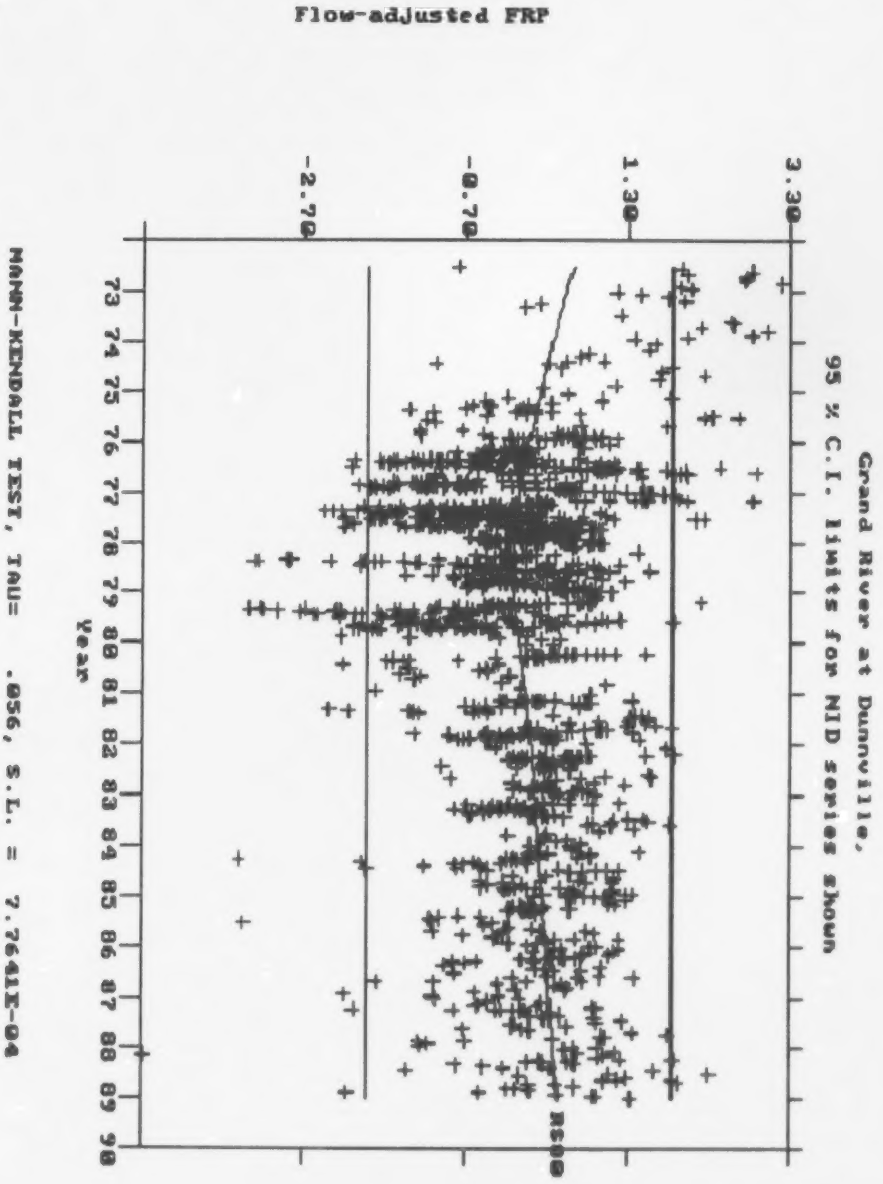
Trend: Significant decline from 1972-1979 with leveling off to fairly constant value from 1980-1989. Statistically significant at 5% and 1% in unadjusted and flow-adjusted data but not significant at 5% in detrended-flow-adjusted data.

Other:

Grand.FRP.2


TRANSFORMED FRP
Grand River at Dunnville, LAMDA = .00
95 % C.I. limits for NID series shown
0.00
-2.00
-4.00
-6.00
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Year
MANN-KENDALL TEST, TAU= .093, S.L. = 0.0000E+00
MS00

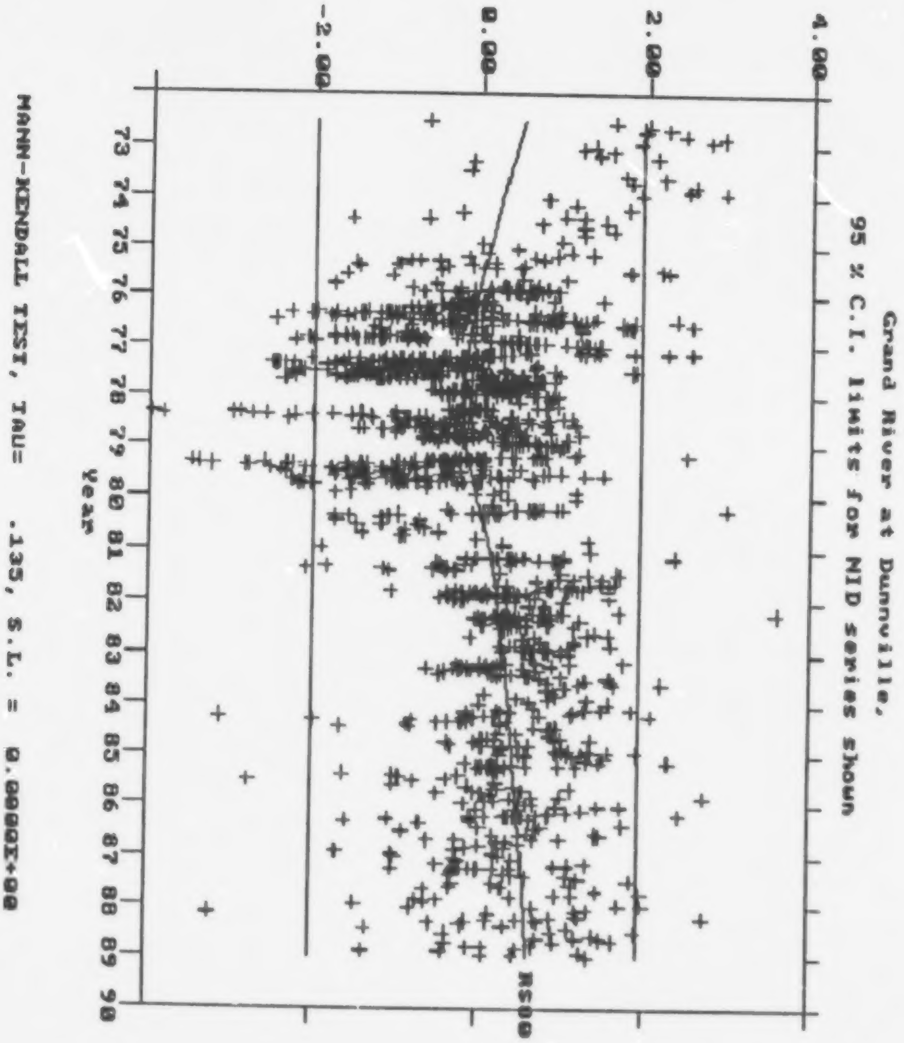
Grand.FRP.3


Flow-adjusted FRP
Grand River at Dunnville,
95 % C.I. limits for NID series shown
3.30
1.30
-0.70
-2.70
73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
Year
MANN-KENDALL TEST, TAU= .056, S.L. = 7.7641E-04

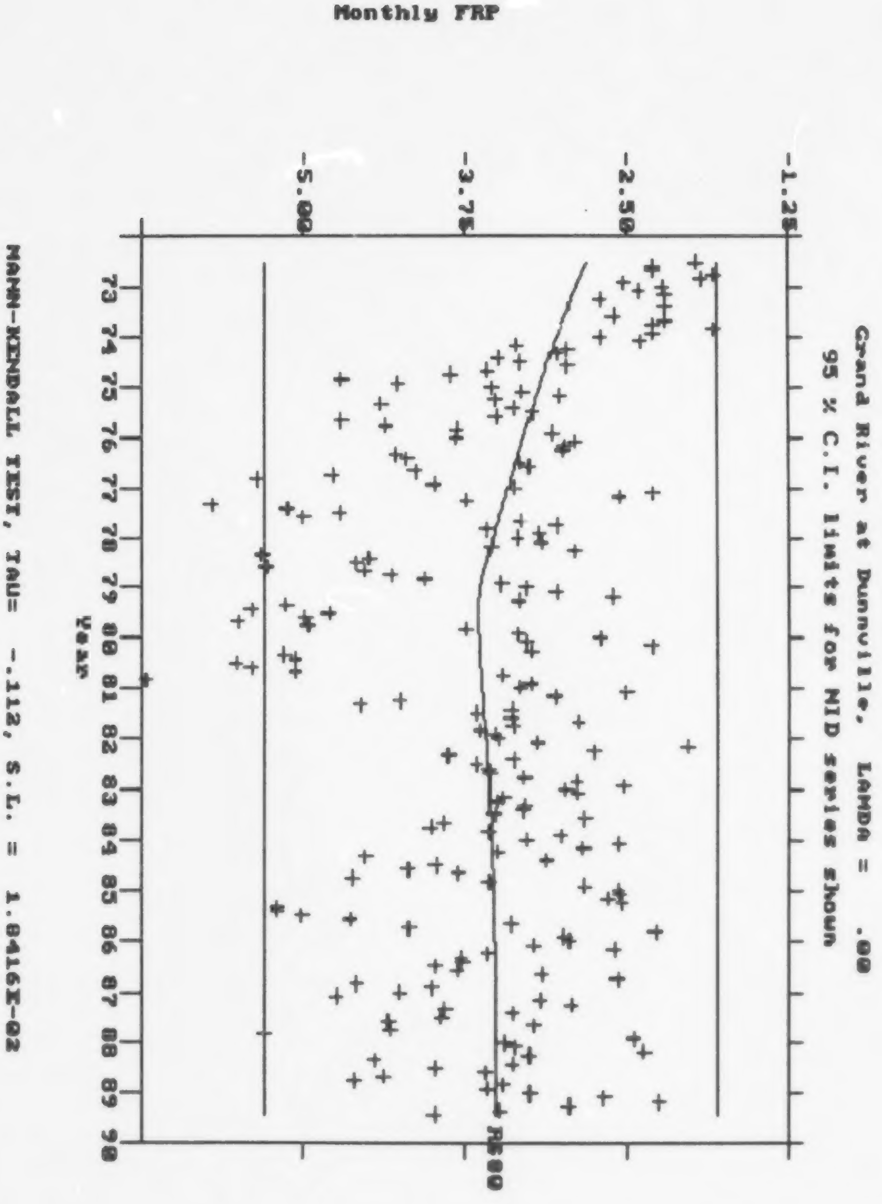
Grand.FRP.4

Detrended

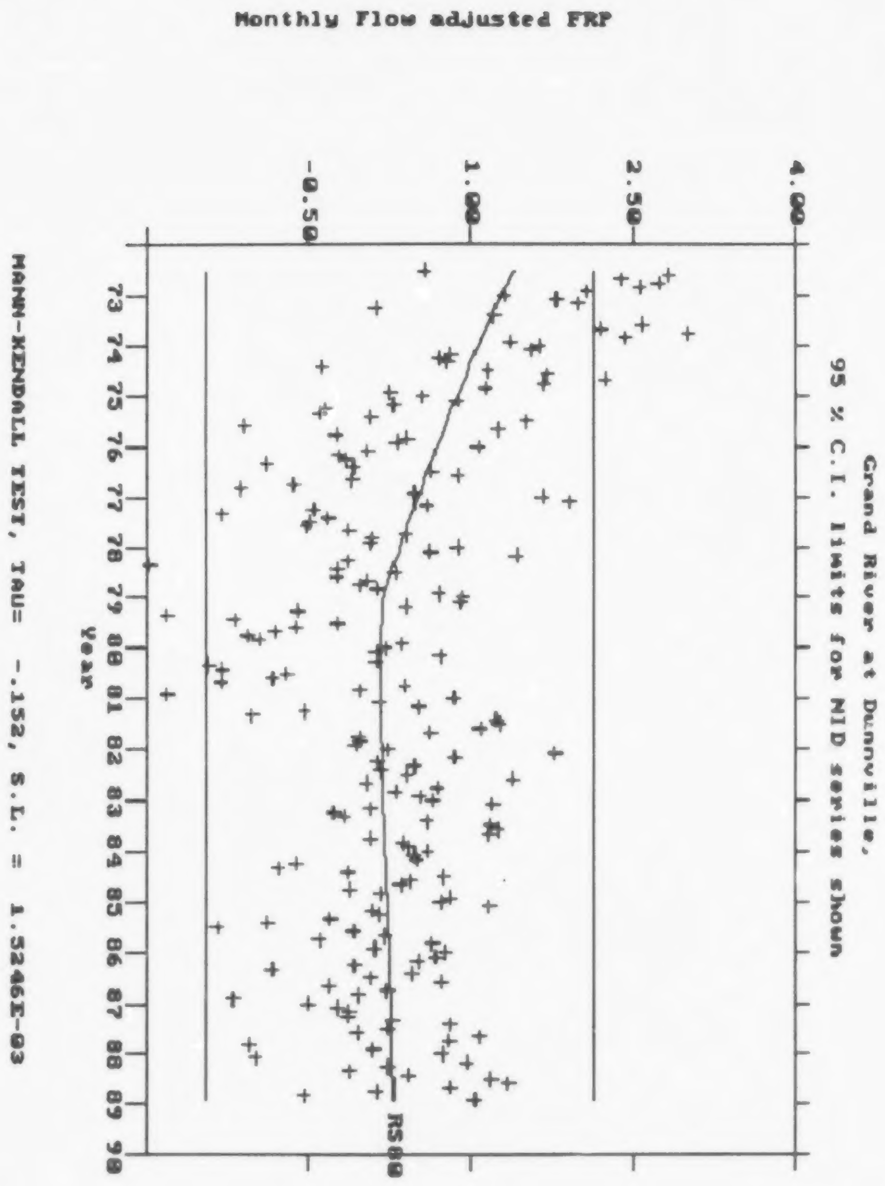
Flow-adjusted FRP



Grand.FRP.5

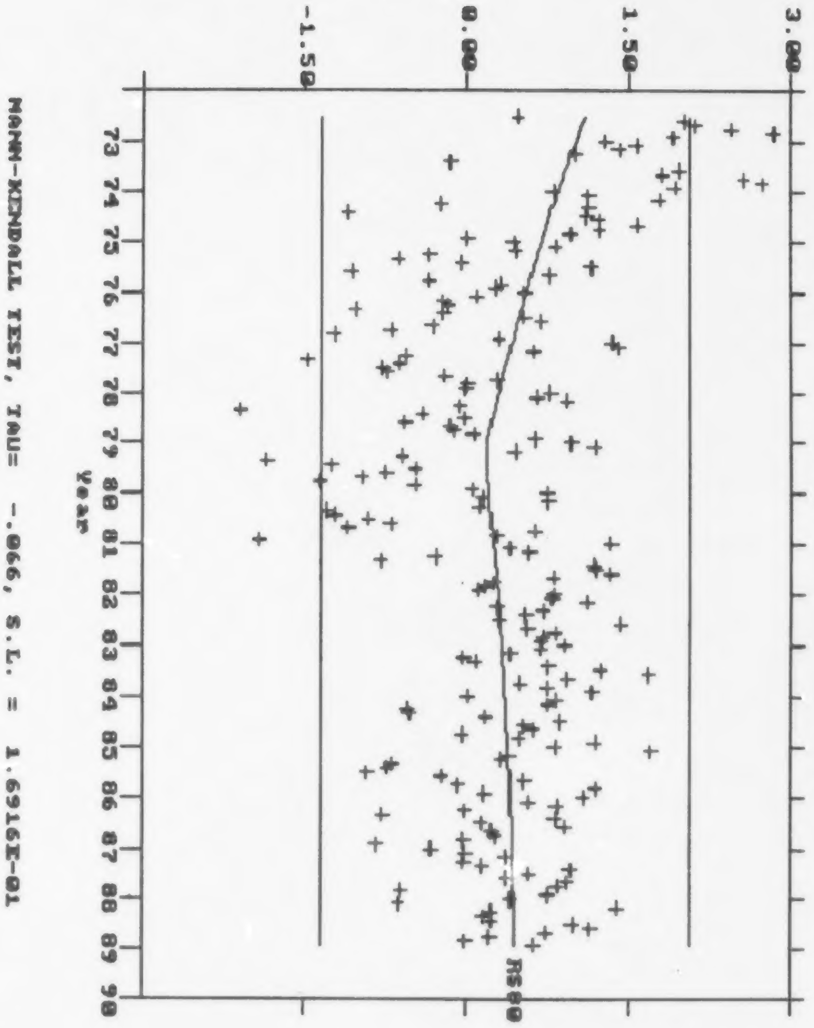

Grand River at Dunnville, LAMDA = .00
95 % C.I. limits for NID series shown
Monthly FRP
-5.00
-3.75
-2.50
-1.25
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Year
MANN-KENDALL TEST, TAU= -.112, S.L. = 1.8416E-02

Grand.FRP.6

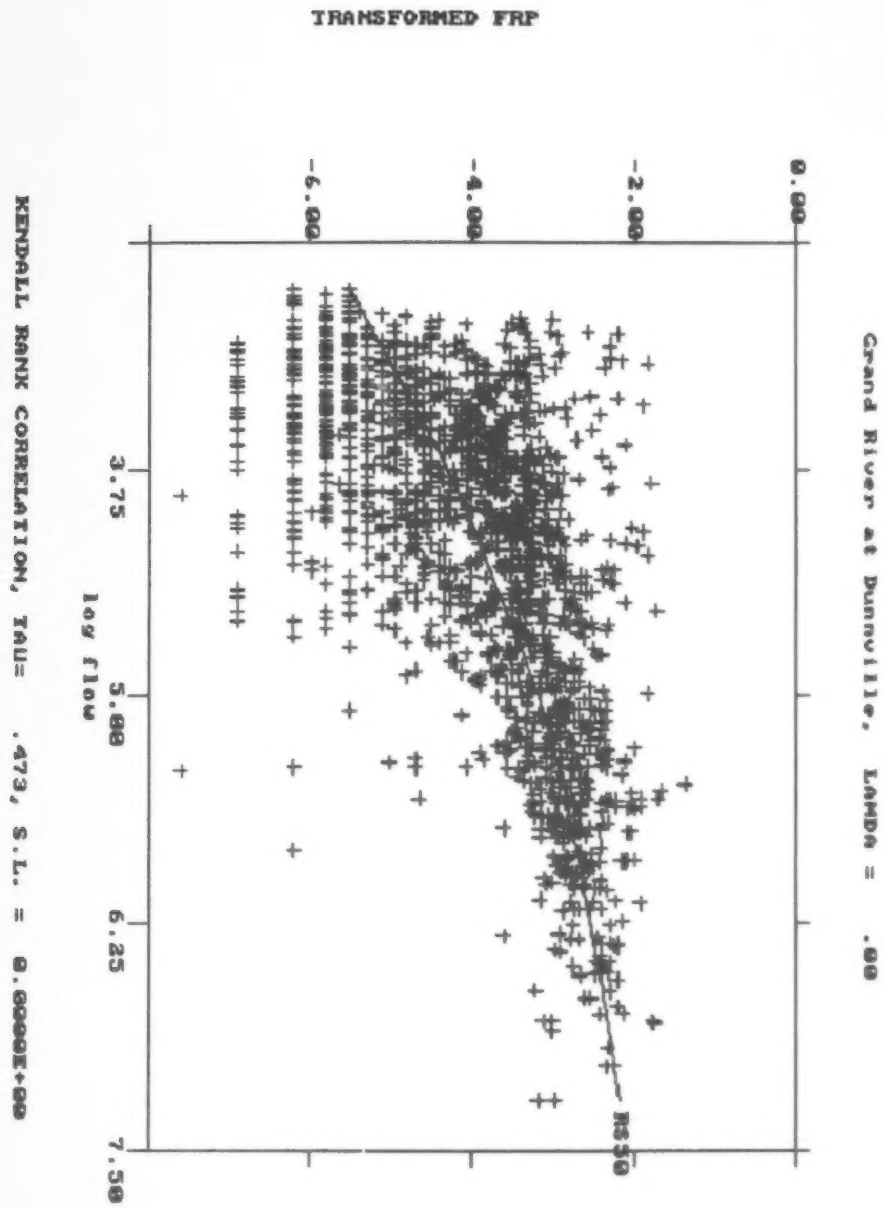

Monthly Flow adjusted FRP
Grand River at Dunnville,
95 % C.I. limits for NID series shown
-0.50
1.00
2.50
4.00
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Year
RS80
MANN-KENDALL TEST, TAU= -.152, S.L. = 1.5246E-03

Grand.FRP.7

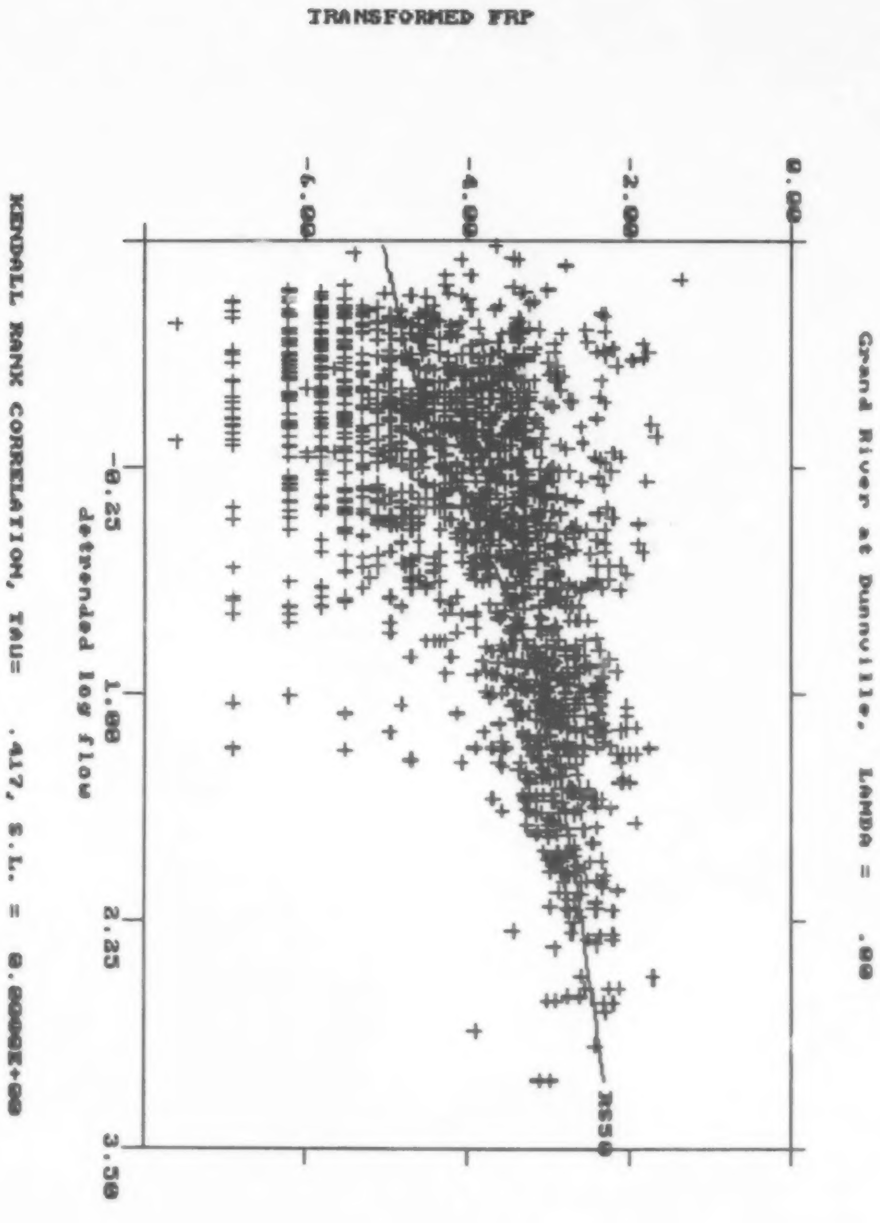
Monthly Flow-detrended FRP



Grand.FRP.8

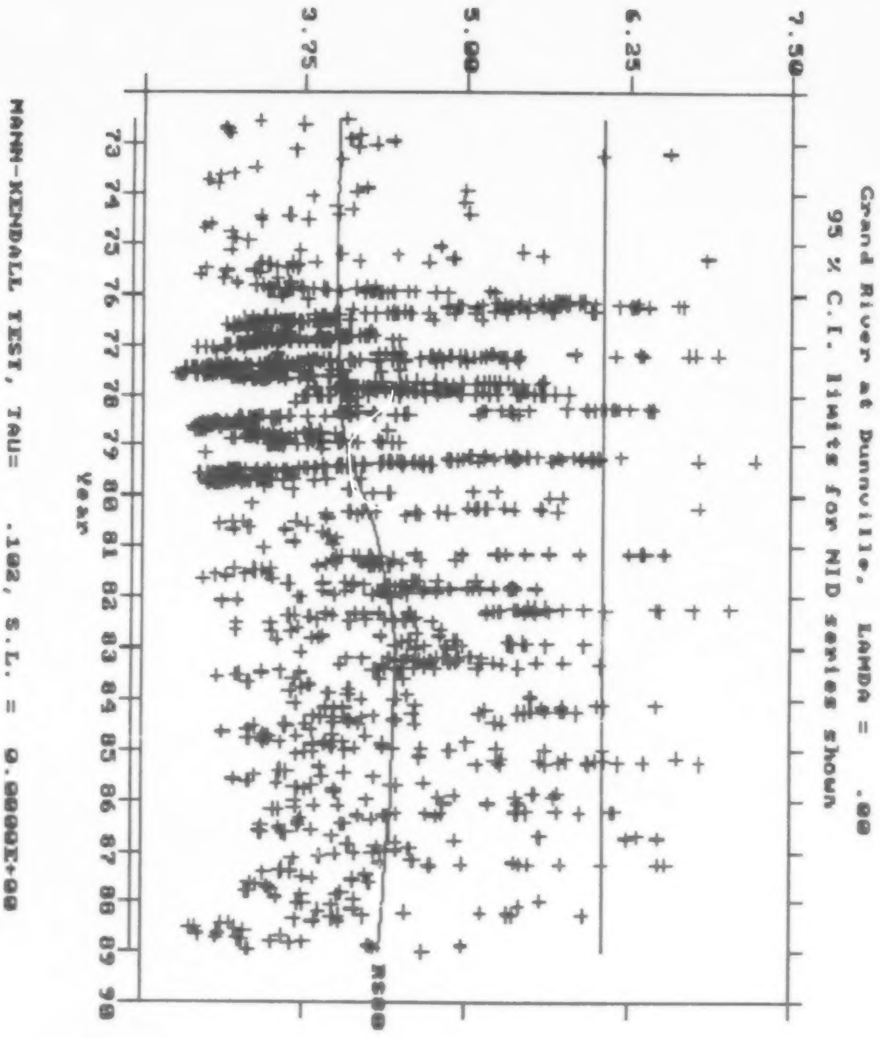

Grand River at Dunnville, LAMDA = .00
TRANSFORMED FRP
0.00
-2.00
-4.00
-6.00
3.75
5.00
6.25
7.50
log flow
NS50
KENDALL RANK CORRELATION, TAU= .473, S.L. = 0.0000E+00

Grand.FRP.9


TRANSFORMED FRP
Grand River at Dunnville, LAMBDA = .00
0.00
-2.00
-4.00
-6.00
-0.25
1.00
2.25
3.50
detrended log flow
RSS
KENDALL RANK CORRELATION, TAU= .417, S.L. = 0.0000E+00

Grand.FRP.10

TRANSFORMED flow @ FRP



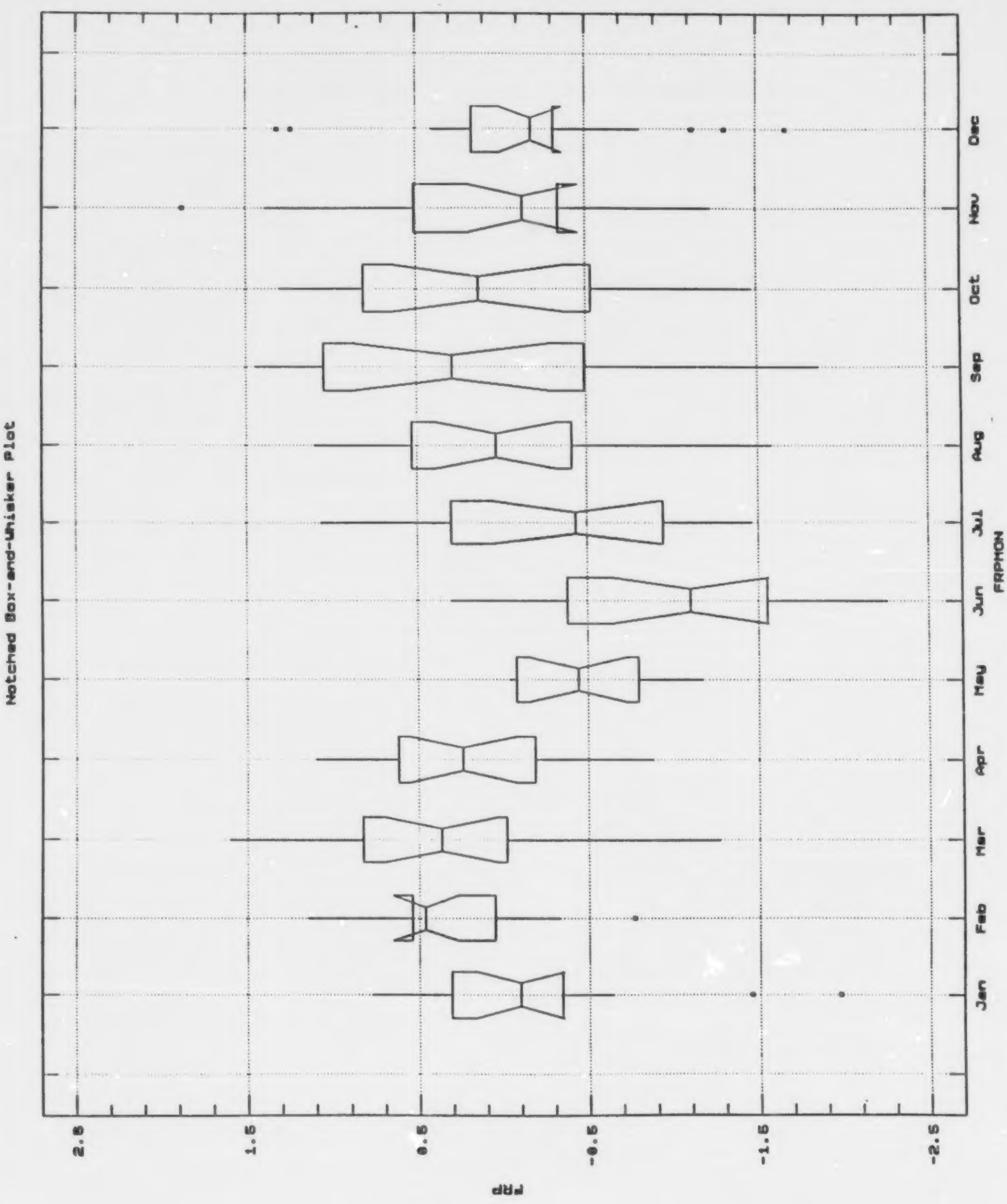
Grand.FRP.11

```
    Trend tests for mean monthly data


    Site: Grand River at Dunnville,

    parameter: FRP

    Basic data - not adjusted for flow


    Mann-Kendall Trend Test
          tau            Significance Level
       -.11168                1.84155E-02


    Ordinary Spearman Trend Test
          rho            Significance Level
       -.16011                2.32125E-02


    Seasonal Mann-Kendall Trend Test
    Score          Variance          Significance Level
    -105.             6875.0                 2.05389E-01


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:   1  2  3  4  5  6  7  8  9 10 11 12
  Rank:  10 10  9  8  7  5  3  1  2  4  6  9

         rho          Significance Level
     -.14662               3.76474E-02
```

GRAND.FRP.12

```
--------------------------------------------------------------------------
Kruskal-Wallis analysis of FRP by FRPMON
--------------------------------------------------------------------------
Level          Sample Size    Average Rank
--------------------------------------------------------------------------
  1               17          163.882  10
  2               17          164.059  10
  3               17          149.176  9
  4               17          127.706  8
  5               16          101.438  7
  6               17          83.2353  5
  7               16          47.8125  3
  8               17          31.6471  1
  9               17          39.0000  2
 10               17           61.6471 4
 11               17           98.4706 6
 12               17           146.765 9
--------------------------------------------------------------------------
Test statistic = 130.558  Significance level  = 0
```

```
      Trend tests for mean monthly data


      Site: Grand River at Dunnville,

      parameter: FRP

      Flow-adjusted Data


      Mann-Kendall Trend Test
            tau          Significance Level
         -.15175              1.52457E-03


      Ordinary Spearman Trend Test
            rho          Significance Level
         -.22906              1.38047E-03


      Seasonal Mann-Kendall Trend Test
      Score            Variance          Significance Level
      -223.               6315.0                  5.01300E-03


      Spearman Trend Test Partialling Out Seasonality

      Seasonal rankings:
  Season:    1  2  3  4  5  6  7  8  9 10 11 12
    Rank:    4  8  7  6  2  1  3  5  6  6  5  3

           rho         Significance Level
       -.22073              2.05404E-03
```


Notched Box-and-Whisker Plot
2.5
1.5
0.5
-0.5
-1.5
-2.5
FRP
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
FRPMON

GRAND.FRP.15

```
--------------------------------------------------------------------
Kruskal-Wallis analysis of FRP by FRPMON
--------------------------------------------------------------------
Level              Sample Size      Average Rank
--------------------------------------------------------------------
   1                   16              95.9375 4
   2                   16              133.188 8
   3                   16              127.313 7
   4                   16              116.875 6
   5                   15              60.4667 2
   6                   16              39.5625 1
   7                   16              81.1875 3
   8                   17              104.706 5
   9                   17              116.059 6
  10                   17              112.588 6
  11                   17              100.176 5
  12                   17              89.6471 3
--------------------------------------------------------------------
Test statistic = 40.6392  Significance level   = 2.77999E-5
```

```
    Trend tests for mean monthly data


    Site: Grand River at Dunnville,

    parameter: FRP

    Flow-adjusted Data


    Mann-Kendall Trend Test
          tau          Significance Level
       -.06604               1.69156E-01


    Ordinary Spearman Trend Test
          rho          Significance Level
       -.10312               1.49870E-01


    Seasonal Mann-Kendall Trend Test
    Score           Variance         Significance Level
     -61.              6315.0                4.42716E-01


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:   1  2  3  4  5  6  7  8  9 10 11 12
  Rank:   5  8  7  8  2  1  3  4  6  6  5  5

         rho          Significance Level
     -.09003               2.08656E-01
```

GRAND.FRP.17

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of FRP by FRPMON
--------------------------------------------------------------------------------
Level        Sample Size     Average Rank
--------------------------------------------------------------------------------
 1              16          102.500  5
 2              16          129.250  8
 3              16          123.563  7
 4              16          129.375  8
 5              15          57.7333  2
 6              16          45.8750  1
 7              16          76.8750  3
 8              17          93.6471  4
 9              17          112.235  6
10              17          109.824  6
11              17          98.5294  5
12              17          98.7647  5
--------------------------------------------------------------------------------
Test statistic = 38.2877  Significance level  = 6.99519E-5
```

Grand.TP

Grand River at Dunnville

Total Phosphorus

Table of Contents: Grand.TP

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs TP

(9) Scatter and smooth of detrended-flow vs TP

(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box-and-whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Summary and Conclusions

Grand River - TP

Data Transformation: logarithmic

Seasonality: very strong

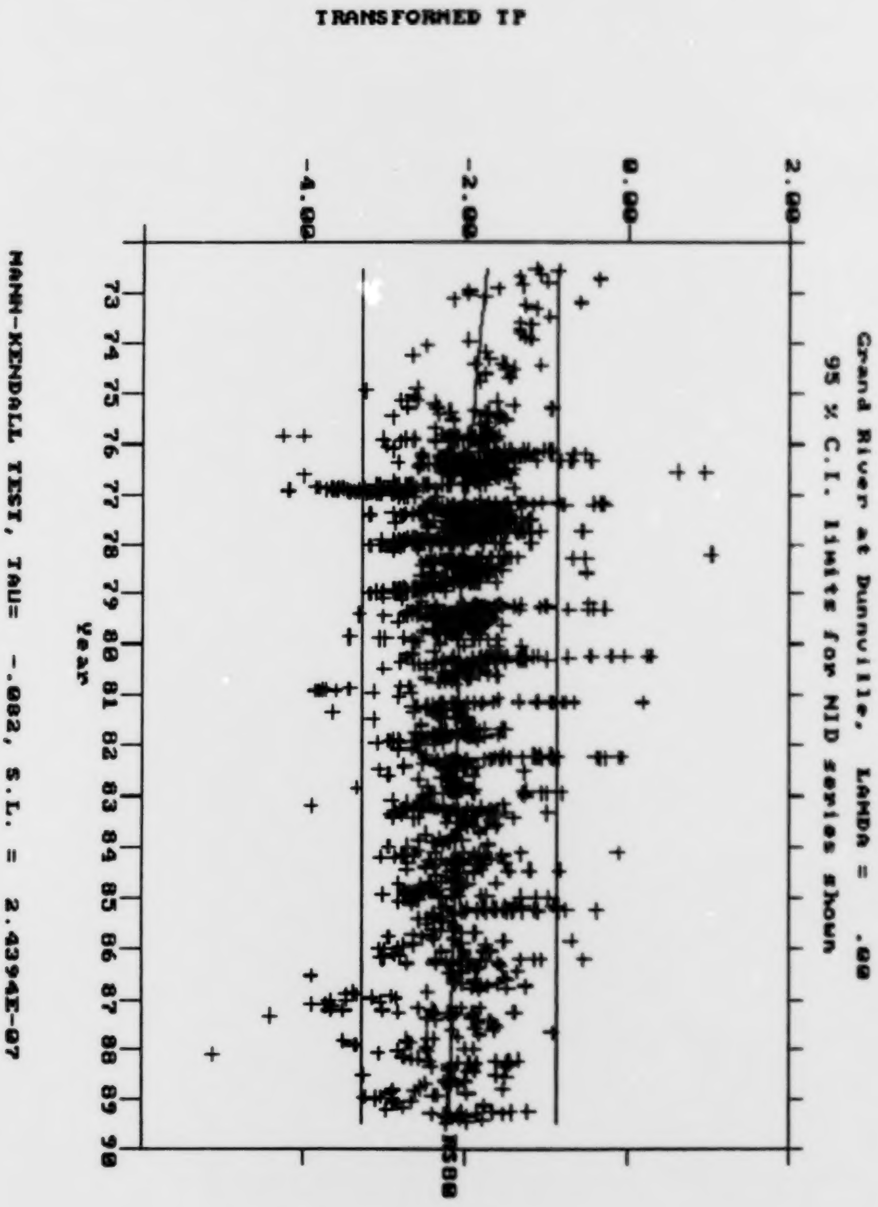
Flow-Concentration Relationship: Positive relationship at higher flows. Slight U-shaped behaviour.

Outliers:

Trend: All methods indicate a highly statistically significant decline. Rapid change downward from 1972-1979. For 1980-1989, there is little change in the unadjusted data but some indication of a slight decline in both the flow-adjusted and detrended-flow-adjusted..

Other:

Grand.TP.2



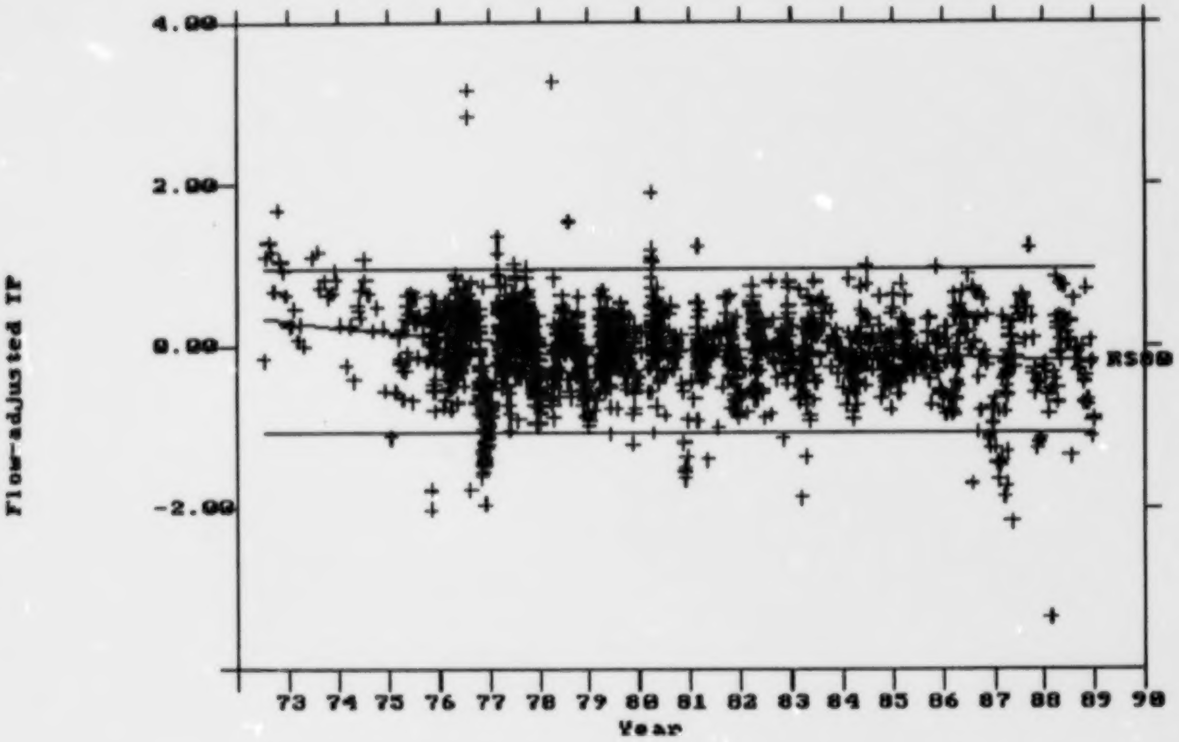
Grand River at Dunnville, LAMDA = .00

95 % C.I. limits for NID series shown

MANN-KENDALL TEST, TAU= -.082, S.L. = 2.4394E-07

Grand.TP.3

Grand River at Dunnville,
95 % C.I. limits for NID series shown

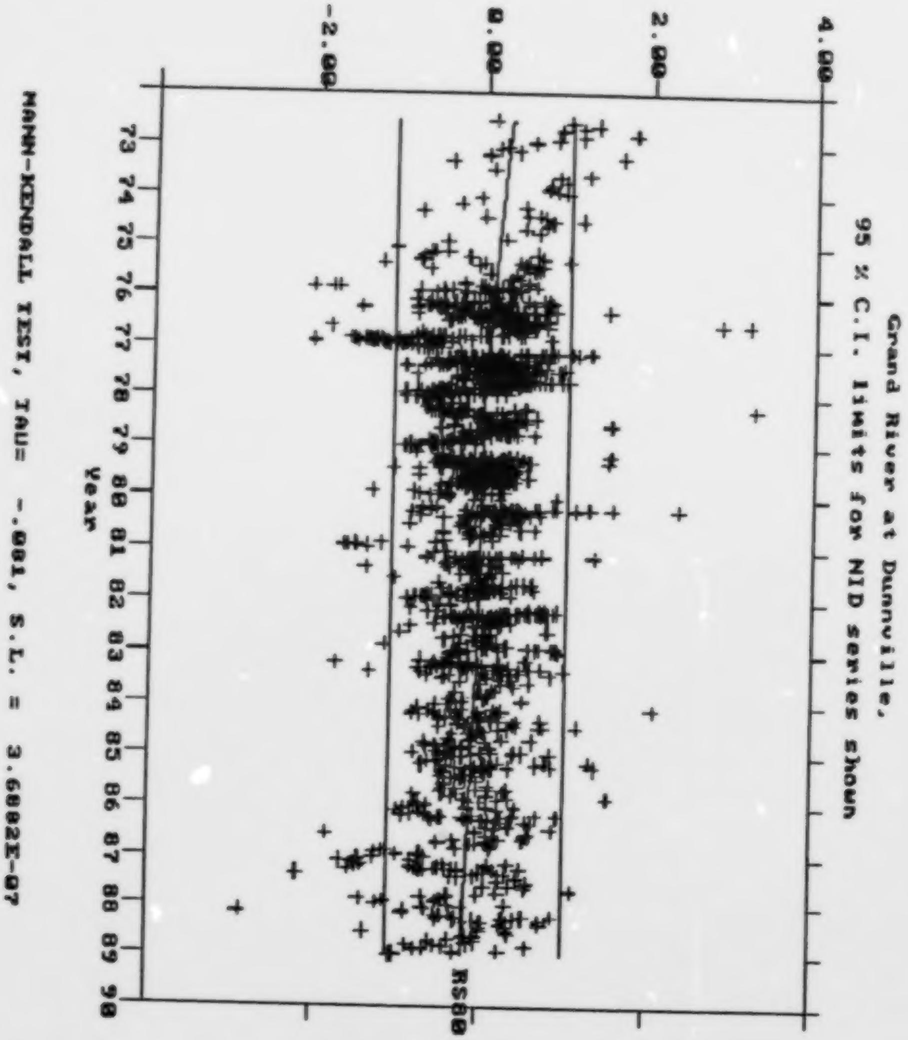


MANN-KENDALL TEST, TAU= -.113, S.L. = 9.0578E-13

Grand.TP.4

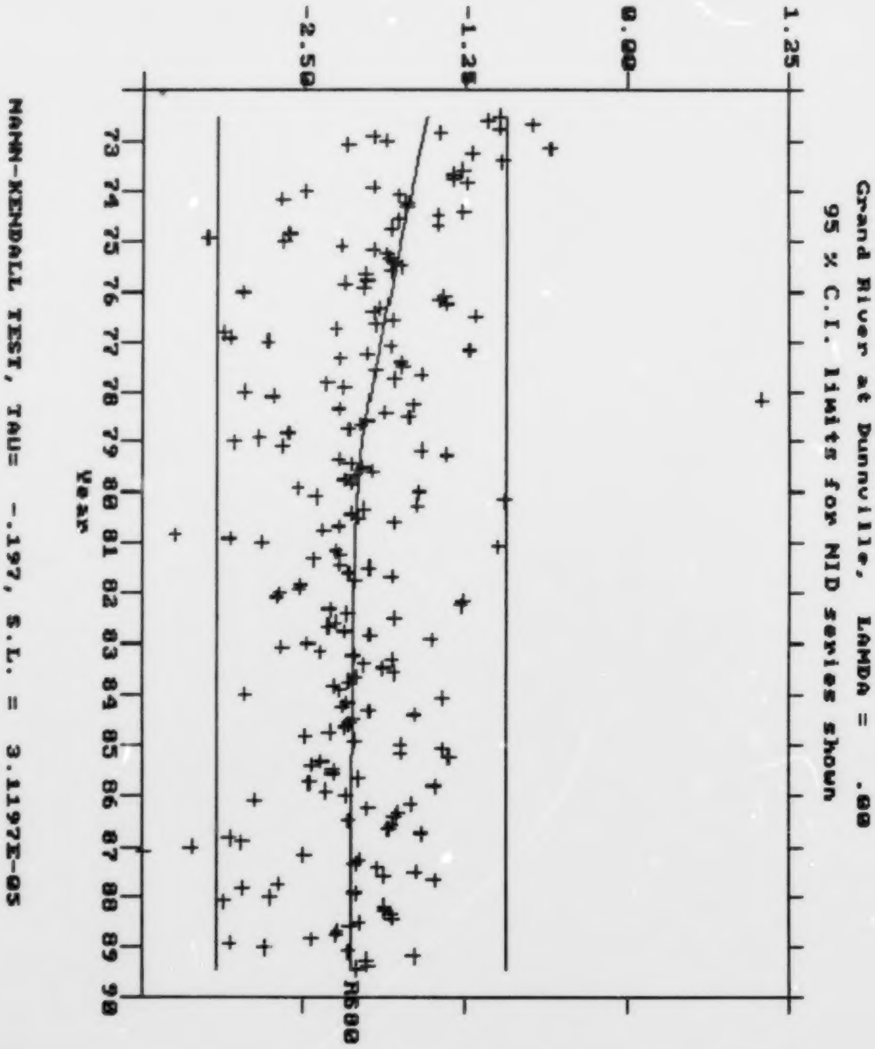
Detrended

Flow-adjusted TP

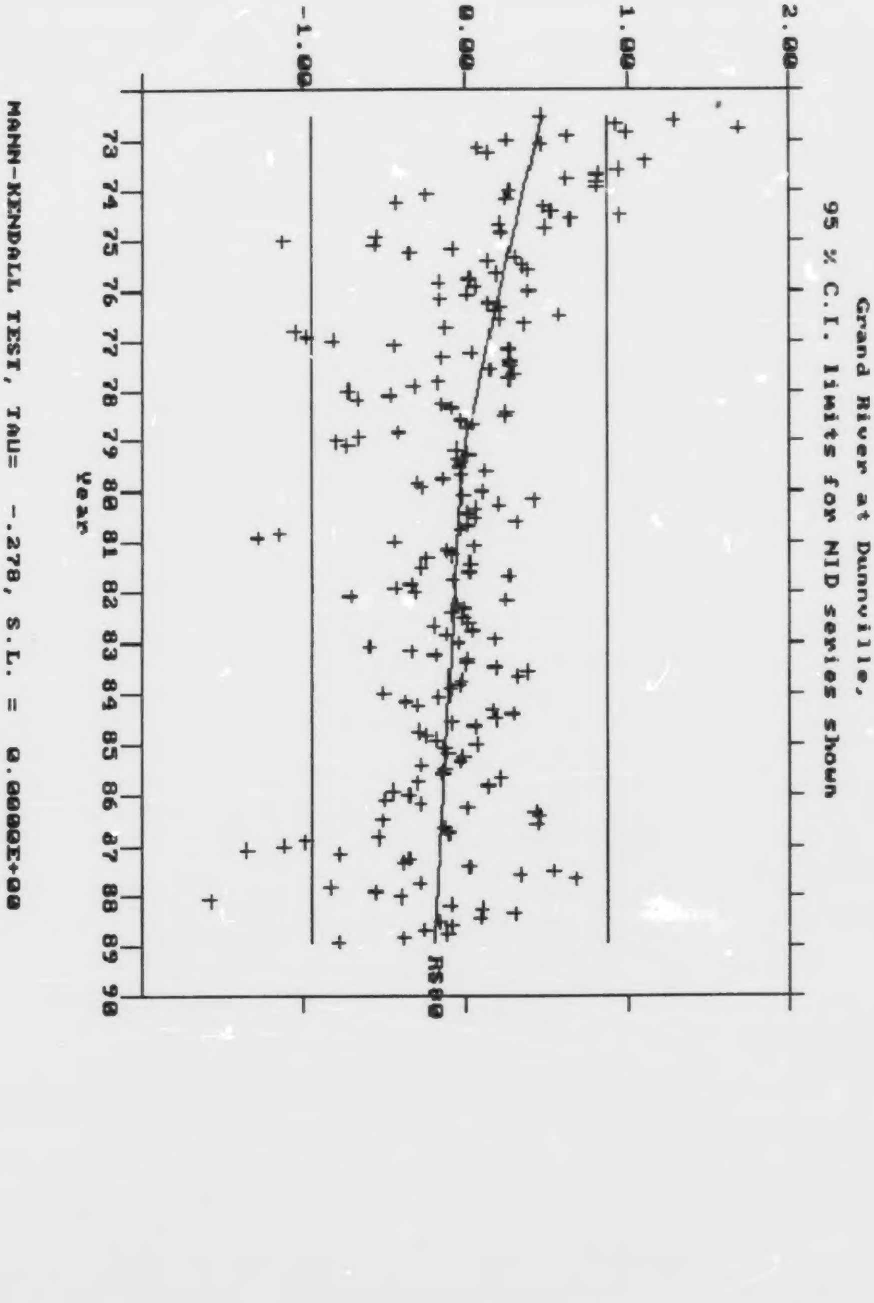


Grand.TP.5

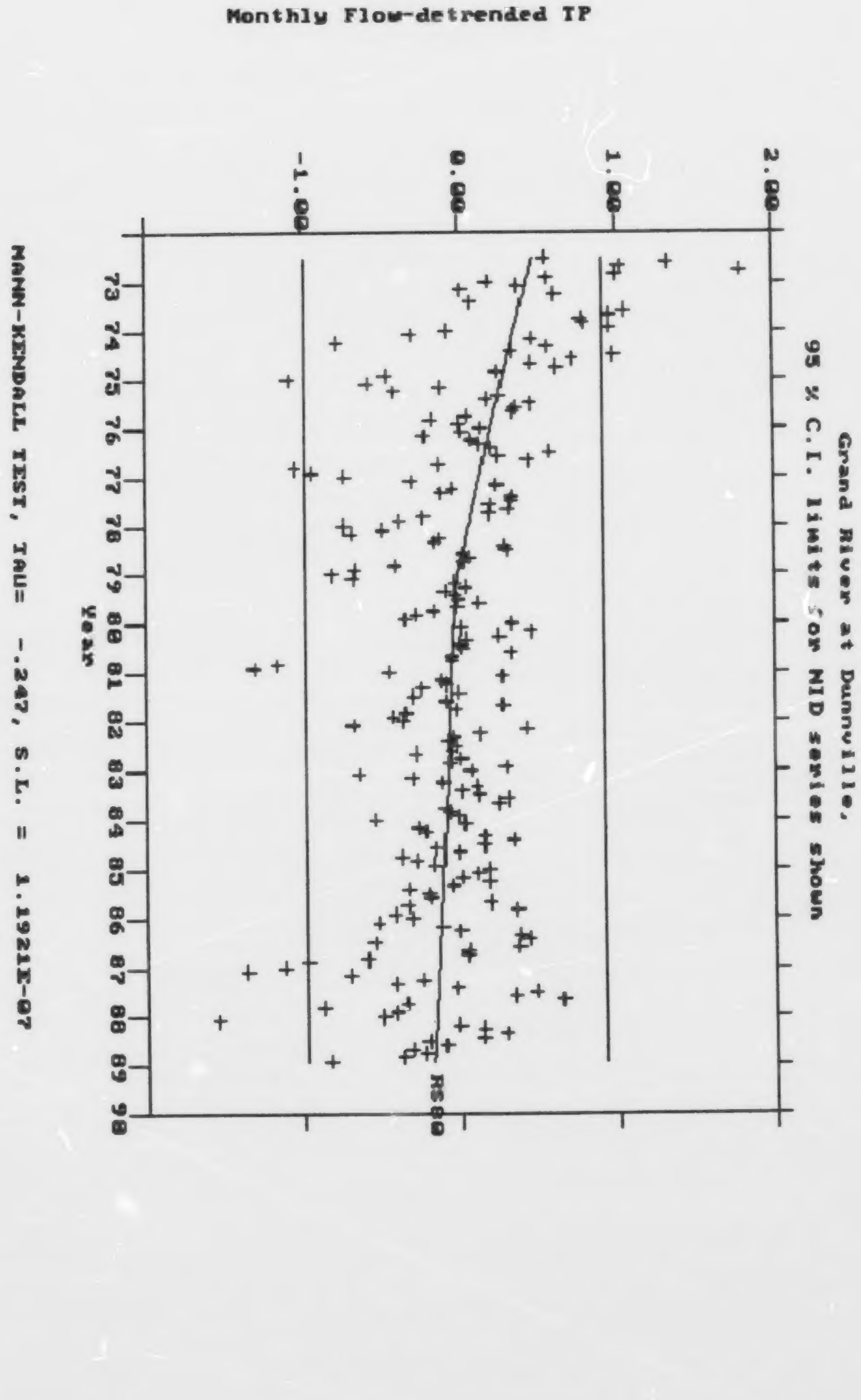
Monthly TP



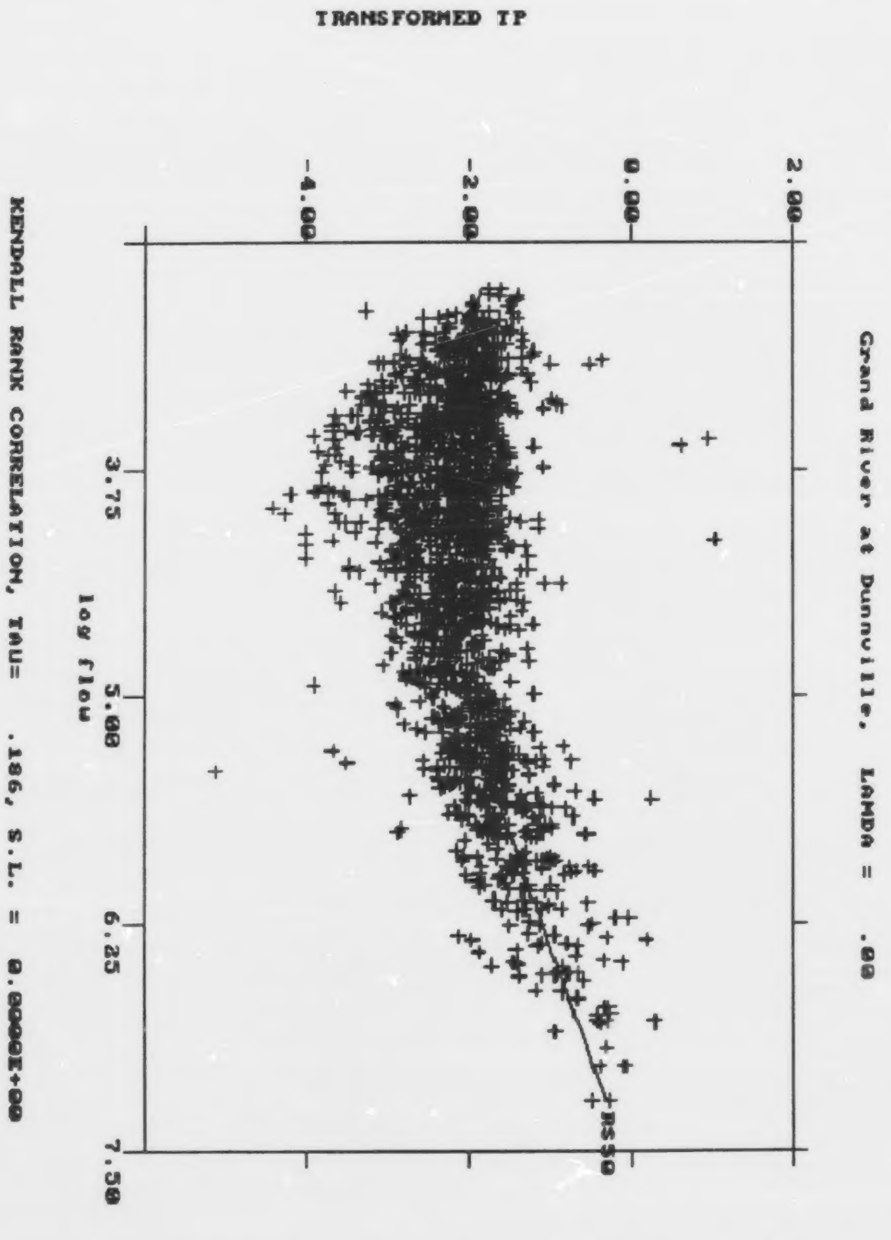
Monthly Flow adjusted TP



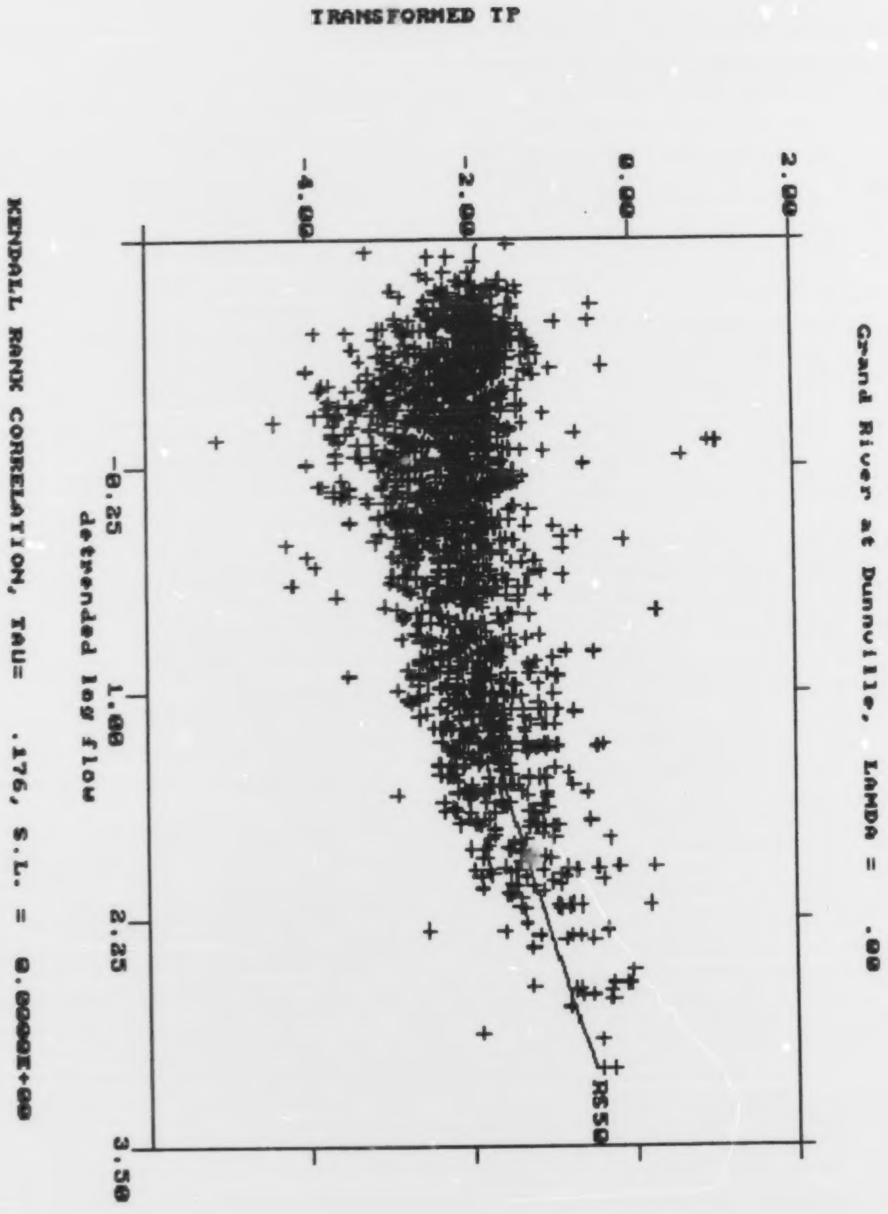
Grand.TP.7


Monthly Flow-detrended TP
Grand River at Dunnville,
95 % C.I. limits for NID series shown
-1.00
0.00
1.00
2.00
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Year
RS80
MANN-KENDALL TEST, TAU= -.247, S.L. = 1.1921E-07

Grand.TP.8

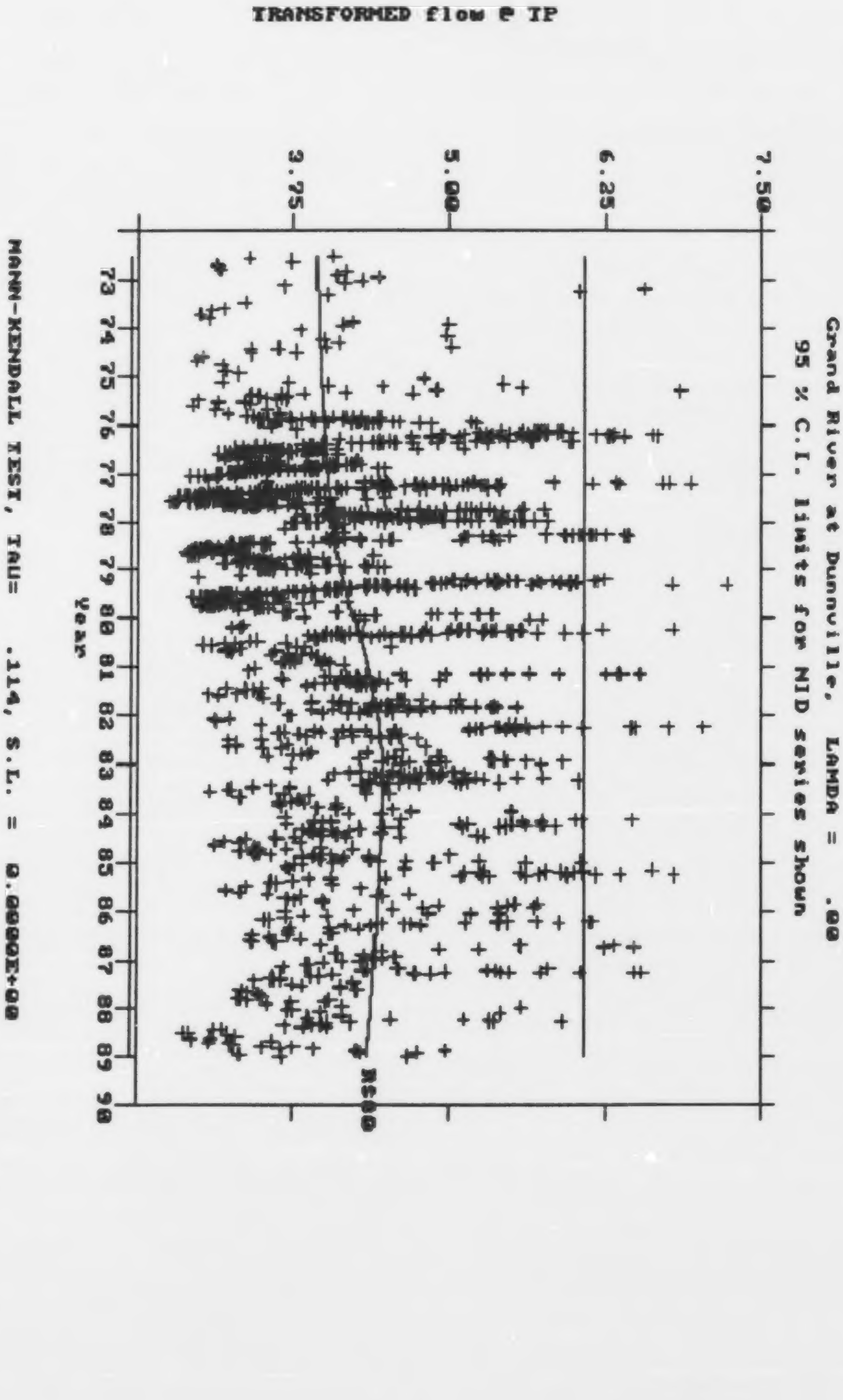

Grand River at Dunnville, LAMDA = .00
TRANSFORMED TP
2.00
0.00
-2.00
-4.00
3.75
5.00
6.25
7.50
log flow
RSSQ
KENDALL RANK CORRELATION, TAU= .186, S.L. = 0.0000E+00

Grand.TP.9



TRANSFORMED TP
Grand River at Dunnville, LAMDA = .00
-4.00
-2.00
0.00
2.00
-0.25
1.00
2.25
3.50
detrended log flow
RS50
KENDALL RANK CORRELATION, TAU= .176, S.L. = 0.0000E+00

Grand.TP.10


TRANSFORMED flow @ TP
Grand River at Dunnville, LAMDA = .00
95 % C.I. limits for MID series shown
3.75
5.00
6.25
7.50
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Year
MEAN
MANN-KENDALL TEST, TAU= .114, S.L. = 0.0000E+00

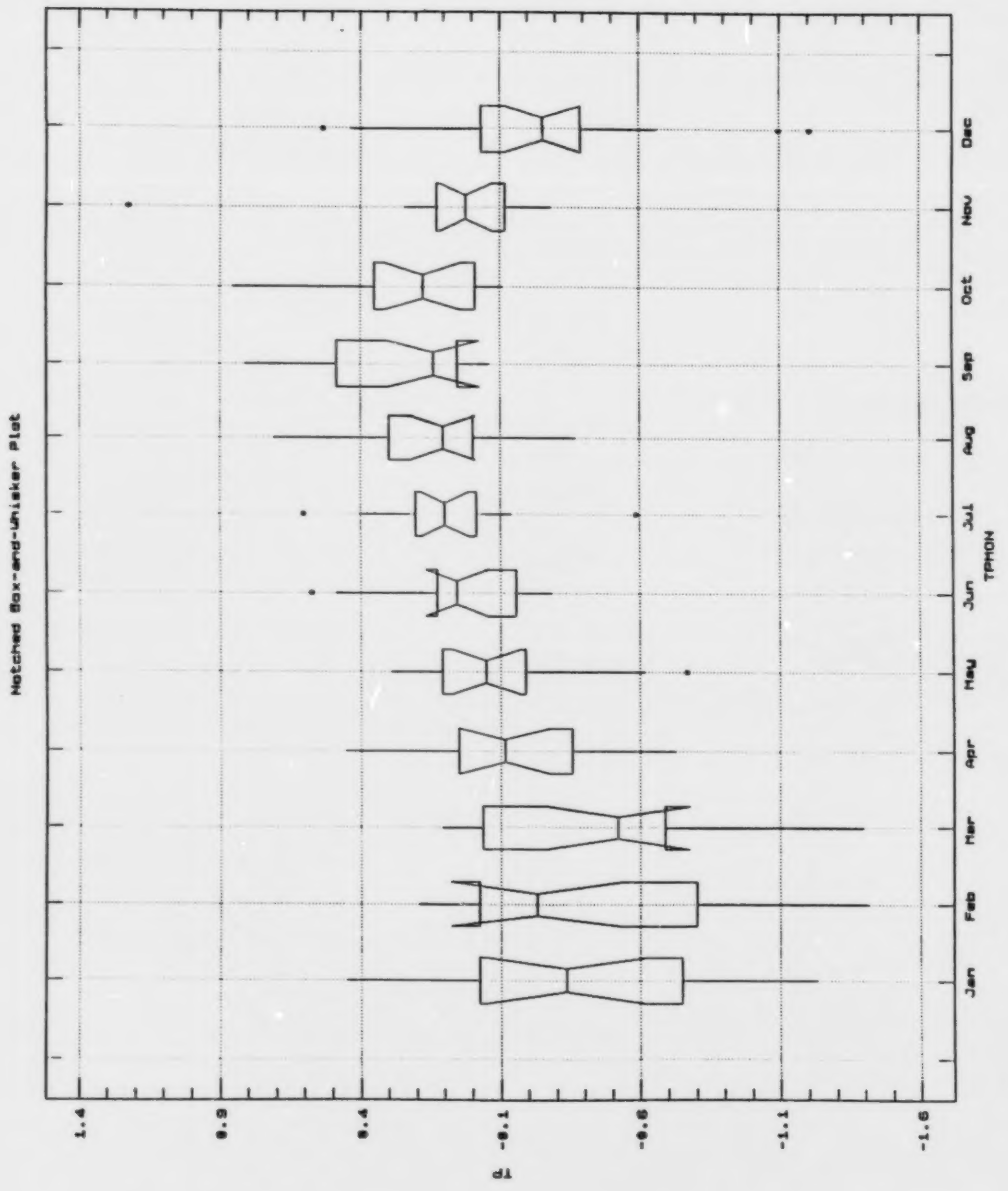
```
    Trend tests for mean monthly data


    Site: Grand River at Dunnville,

    parameter: TP

    Basic data - not adjusted for flow


    Mann-Kendall Trend Test
          tau          Significance Level
       -.19721              3.11973E-05


    Ordinary Spearman Trend Test
          rho          Significance Level
       -.28963              4.02119E-05


    Seasonal Mann-Kendall Trend Test
    Score          Variance             Significance Level
    -434.             6878.0                    1.66695E-07


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    2  1  4  8  8  6  7  9  7  7  5  3

         rho         Significance Level
     -.29572              2.75830E-05
```

GRAND.TP.12

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of TP by TPMON
--------------------------------------------------------------------------------
Level        Sample Size    Average Rank
--------------------------------------------------------------------------------
  1              17            54.4118  2
  2              17            44.2353  1
  3              17            79.0000  4
  4              17            138.059  8
  5              16            136.938  8
  6              17            105.529  6
  7              16            121.125  7
  8              17            141.235  9
  9              17            122.882  7
 10               17            120.706  7
 11               17            92.8824  5
 12               17            64.2353  3
--------------------------------------------------------------------------------
Test statistic = 63.5188  Significance level  = 2.04442E-9
```

```
    Trend tests for mean monthly data


    Site: Grand River at Dunnville,

    parameter: TP

    Flow-adjusted Data


    Mann-Kendall Trend Test
          tau          Significance Level
       -.27849              0.00000E+00


    Ordinary Spearman Trend Test
          rho          Significance Level
       -.38867              5.71482E-08


    Seasonal Mann-Kendall Trend Test
    Score          Variance          Significance Level
    -487.             6315.0                8.88053E-10


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:   1  2  3  4  5  6  7  8  9 10 11 12
  Rank:   2  2  1  4  5  6  7  8  9  8  6  3

         rho         Significance Level
     -.42165              3.90803E-09
```

Grand.TP.14


Notched Box-and-Whisker Plot
TP
TPMON
1.4
0.9
0.4
-0.1
-0.6
-1.1
-1.6
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

GRAND.TP.15

```
---------------------------------------------------------------------
Kruskal-Wallis analysis of TP by TPMON
---------------------------------------------------------------------
Level                Sample Size      Average Rank
---------------------------------------------------------------------
  1                      16              62.0625 2
  2                      16              60.3125 2
  3                      16              49.3750 1
  4                      16              80.4375 4
  5                      15              92.0667 5
  6                      16              111.875 6
  7                      16              124.313 7
  8                      17              134.000 8
  9                      17              146.471 9
 10                      17              134.706 8
 11                      17              108.235 6
 12                      17              71.3529 3
---------------------------------------------------------------------
Test statistic = 62.0077  Significance level  = 3.91977E-9
```

```
    Trend tests for mean monthly data

    Site: Grand River at Dunnville,

    parameter: TP

    Flow-adjusted Data

    Mann-Kendall Trend Test
          tau           Significance Level
       -.24731                1.19209E-07

    Ordinary Spearman Trend Test
          rho           Significance Level
       -.35152                9.16514E-07

    Seasonal Mann-Kendall Trend Test
    Score            Variance          Significance Level
    -455.               6315.0                1.03039E-08

    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:     1  2  3  4  5  6  7  8  9 10 11 12
  Rank:     2  1  1  4  5  7  7  8  9  9  6  3

        rho           Significance Level
     -.37320                1.87399E-07
```

GRAND.TP.17

```
------------------------------------------------------------------
Kruskal-Wallis analysis of TP by TPMON
------------------------------------------------------------------
Level          Sample Size    Average Rank
------------------------------------------------------------------
  1              16            63.9375  2
  2              16            56.0000  1
  3              16            57.0625  1
  4              16            90.6250  4
  5              15            97.0000  5
  6              16            113.063  7
  7              16            118.625  7
  8              17            121.941  8
  9              17            140.529  9
 10              17            139.294  9
 11              17            104.941  6
 12              17            73.4118  3
------------------------------------------------------------------
Test statistic = 51.4202  Significance level  = 3.47151E-7
```

Grand.SS

Grand River at Dunnville

Suspended Solids

Table of Contents: Grand.SS

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs SS

(9) Scatter and smooth of detrended-flow vs SS

(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box-and-whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Summary and Conclusions

Grand River - SS

Data Transformation: logarithmic

Seasonality: very strong

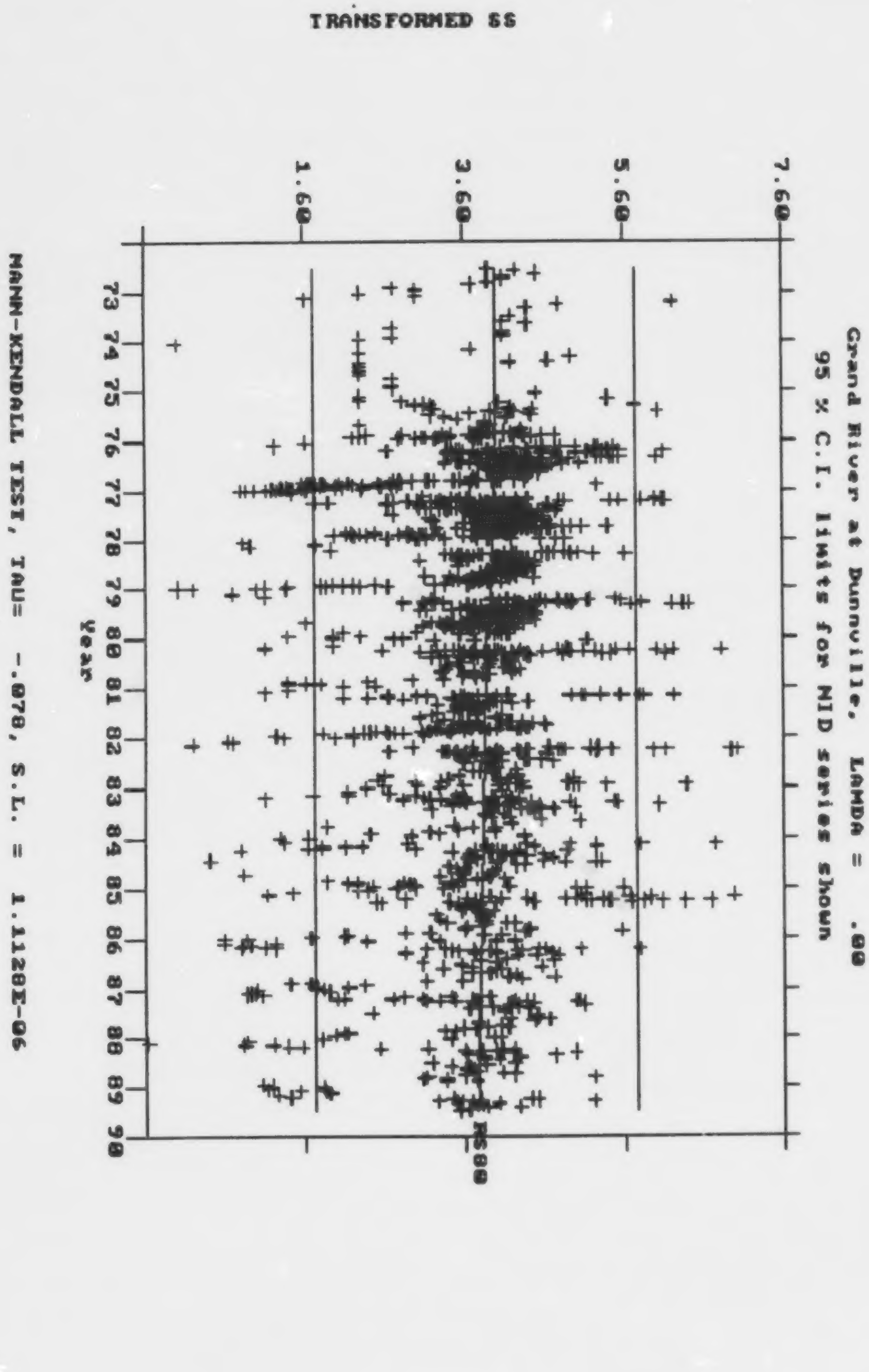
Flow-Concentration Relationship: Unusual two-branch behaviour at low flow due to seasonal effects. More refined model called for.

Outliers:

Trend: No trends.

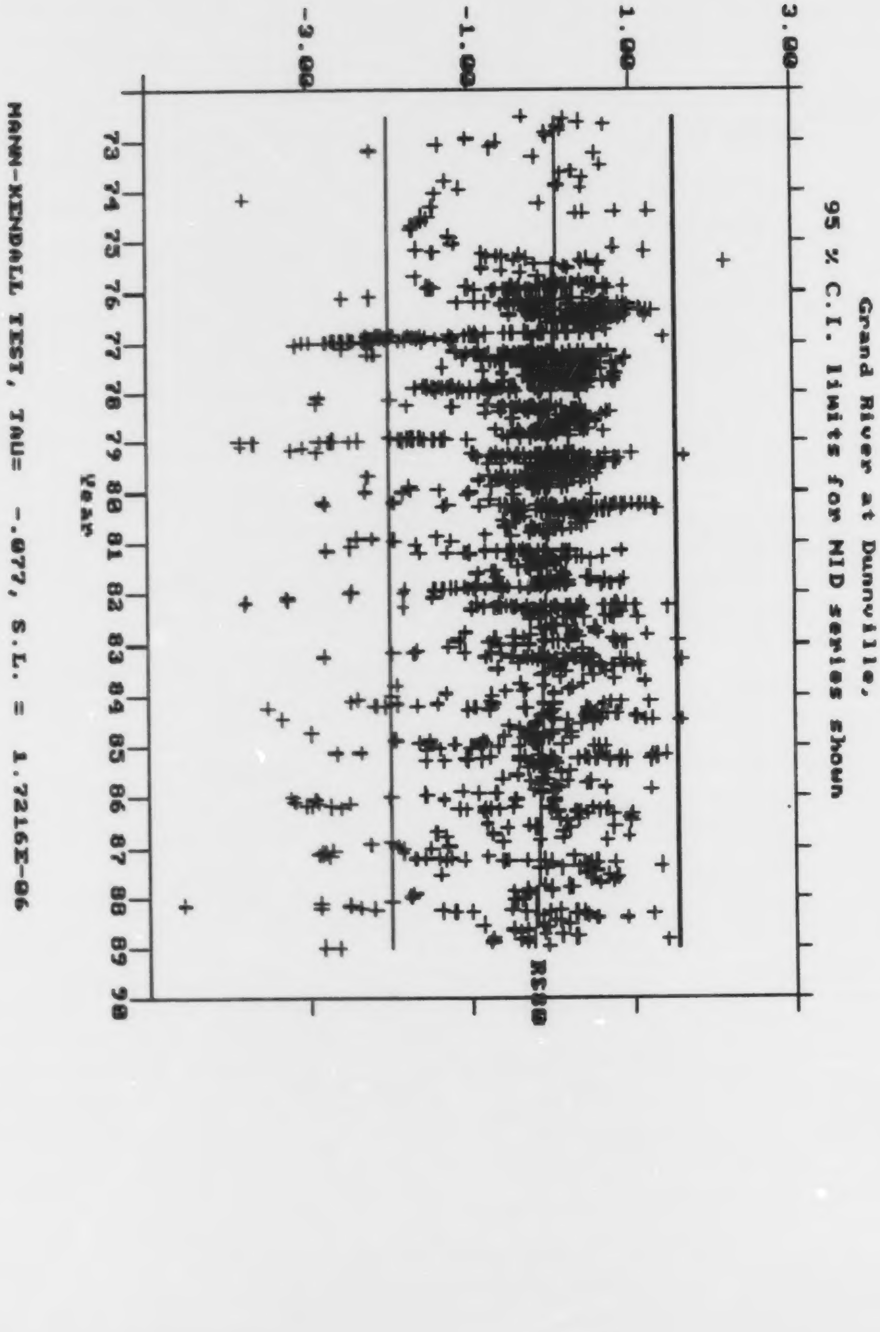
Other:

Grand.SS.2


TRANSFORMED SS
Grand River at Dunnville, LAMDA = .00
95 % C.I. limits for NID series shown
1.60
3.60
5.60
7.60
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Year
RS88
MANN-KENDALL TEST, TAU= -.078, S.L. = 1.1128E-06

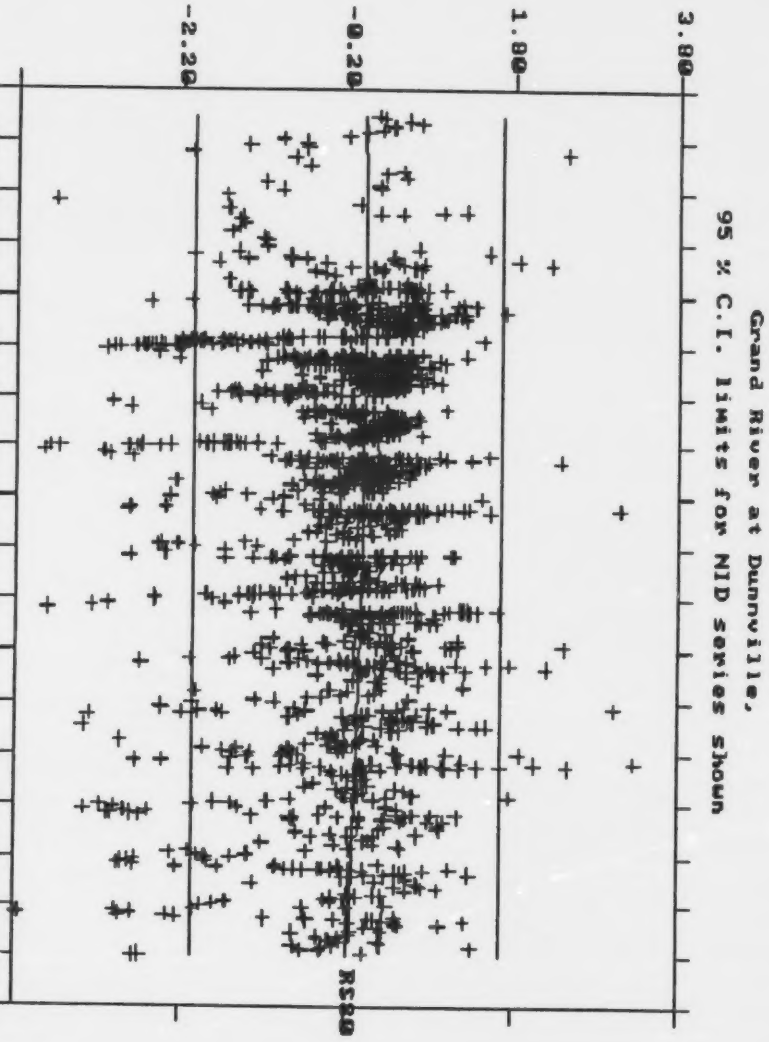
Grand.SS.3

Flow-adjusted SS



Detrended

Flow-adjusted SS

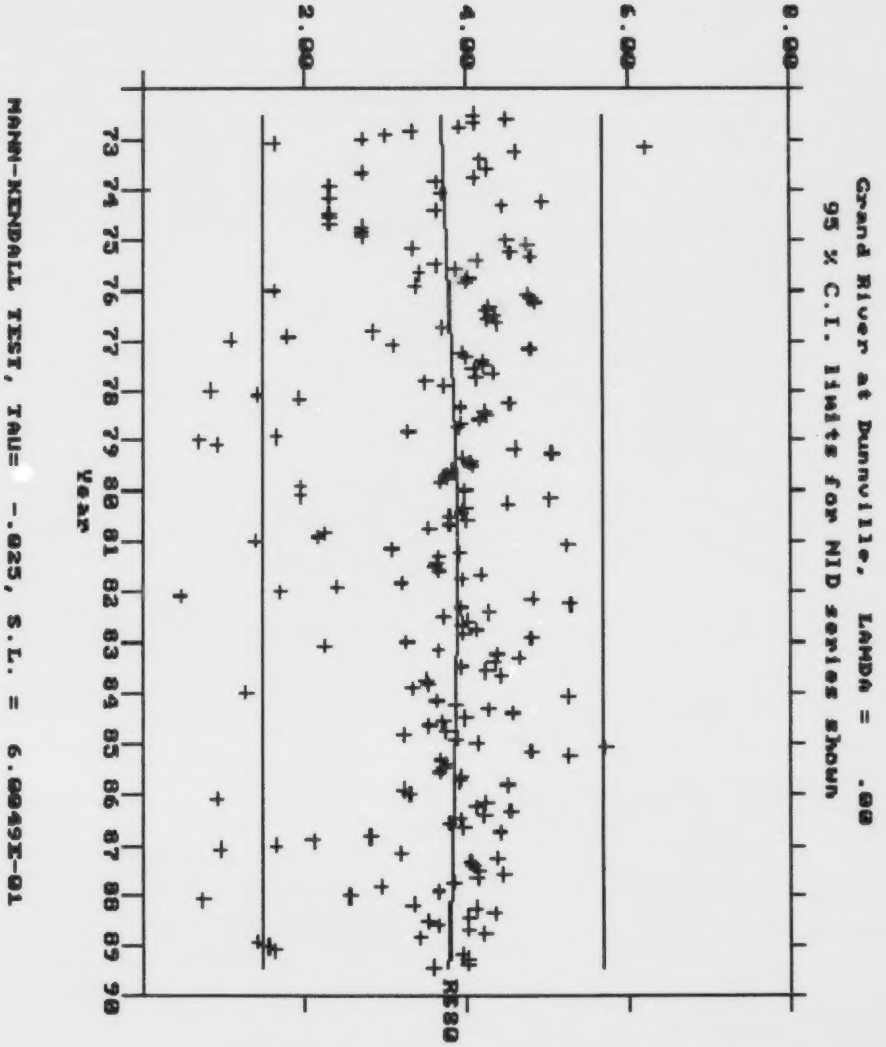


Grand River at Dunnville,
95 % C.I. limits for NID series shown

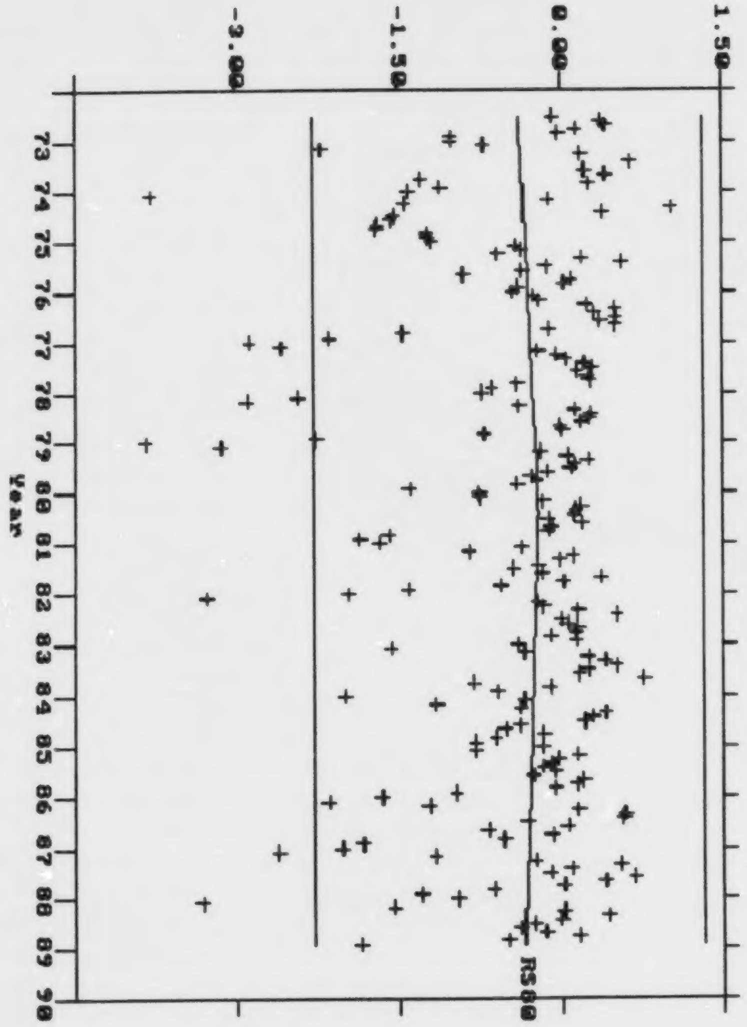
MANN-KENDALL TEST, TAU= -.060, S.L. = 1.8669E-04

Grand.SS.5

Monthly SS



Monthly Flow adjusted SS

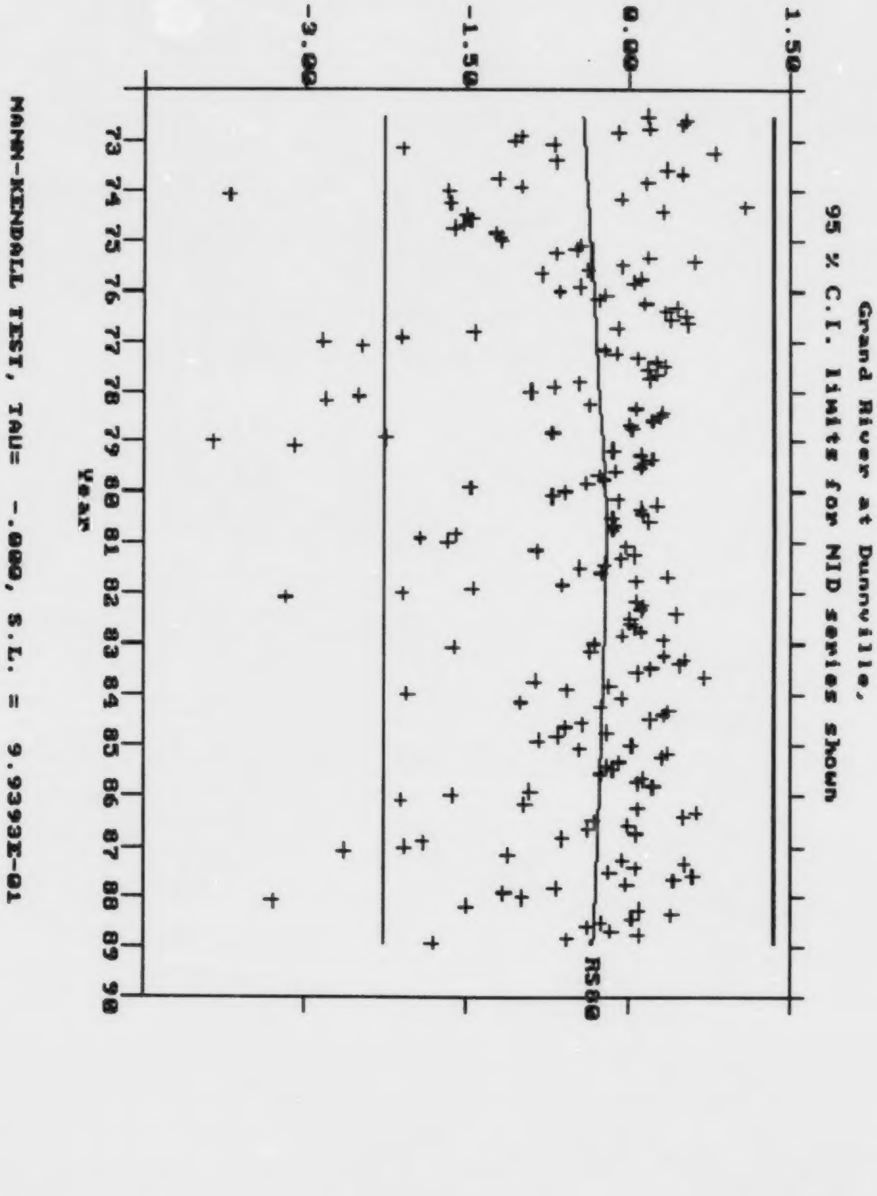


Grand River at Dunnville,
95 % C.I. limits for NID series shown

MANN-KENDALL TEST, TAU= -.011, S.L. = 0.1172E-01

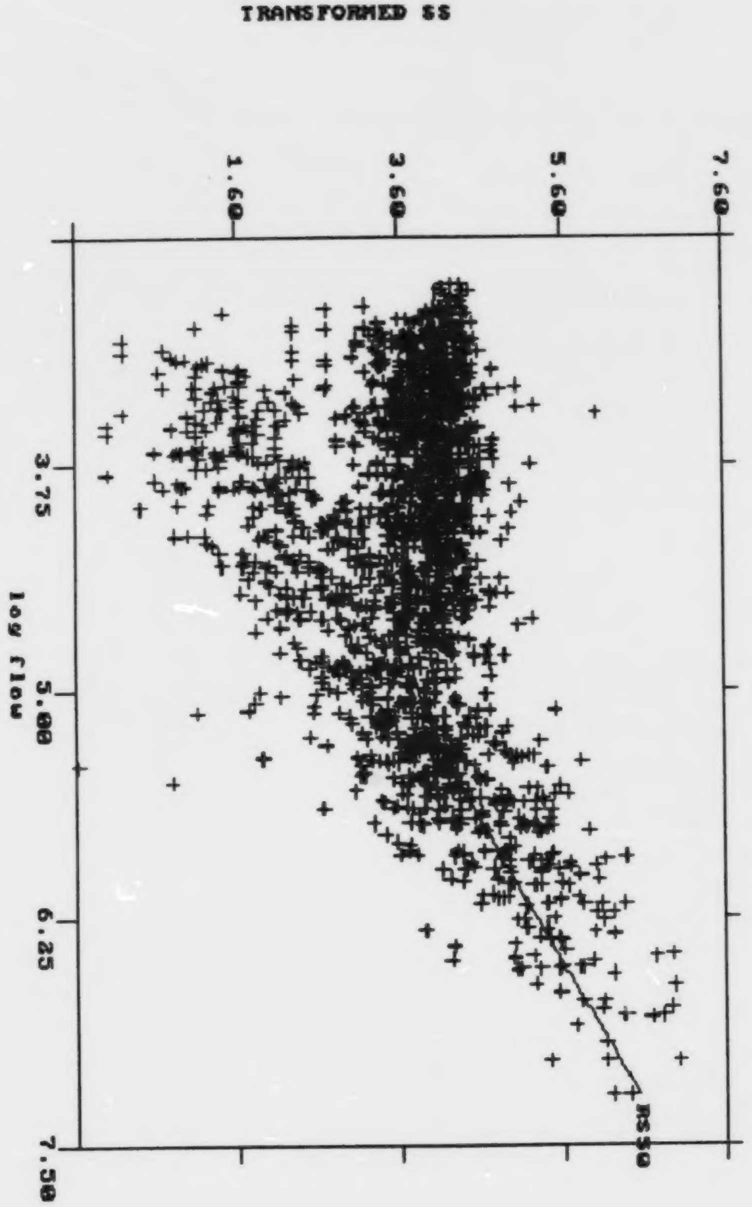
Grand.SS.7

Monthly Flow-detrended SS



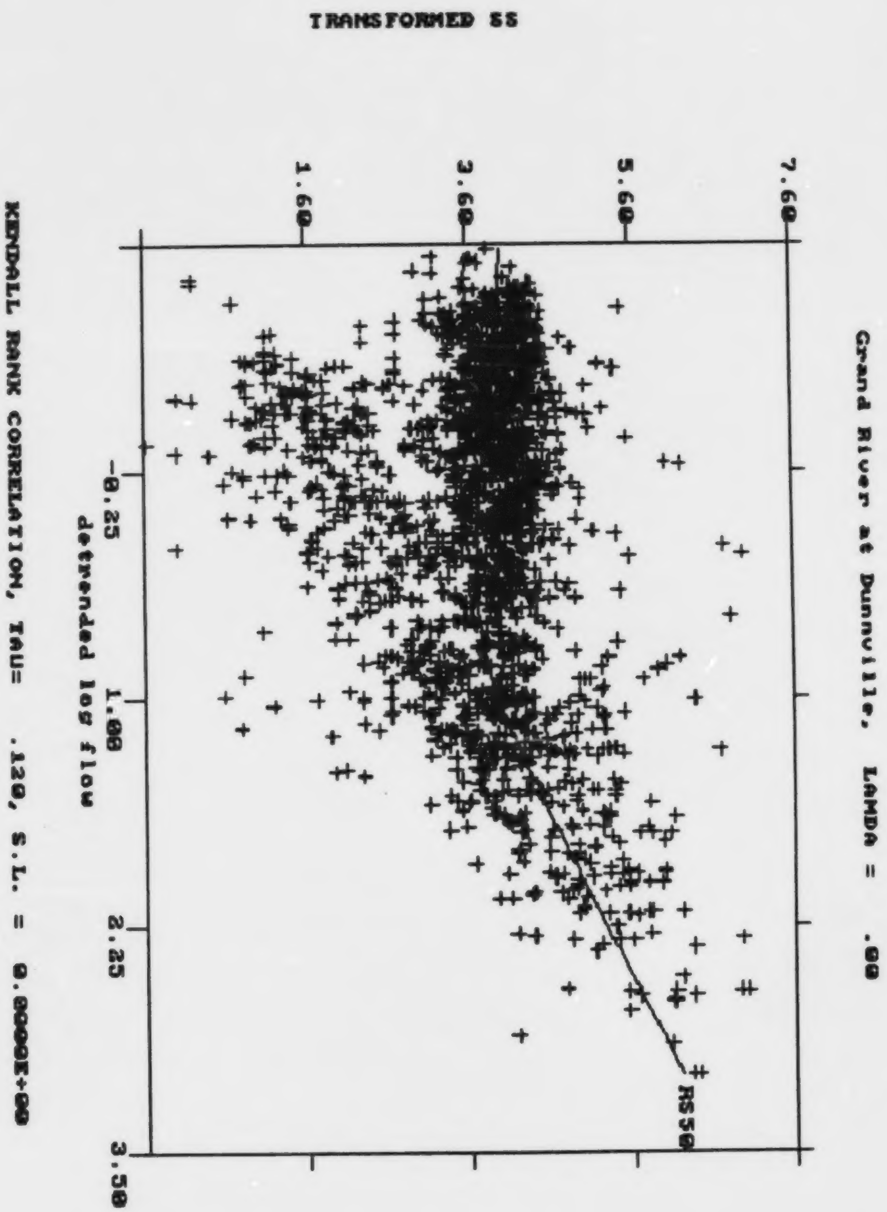
Grand.SS.8

Grand River at Dunnville, LAMDA = .00

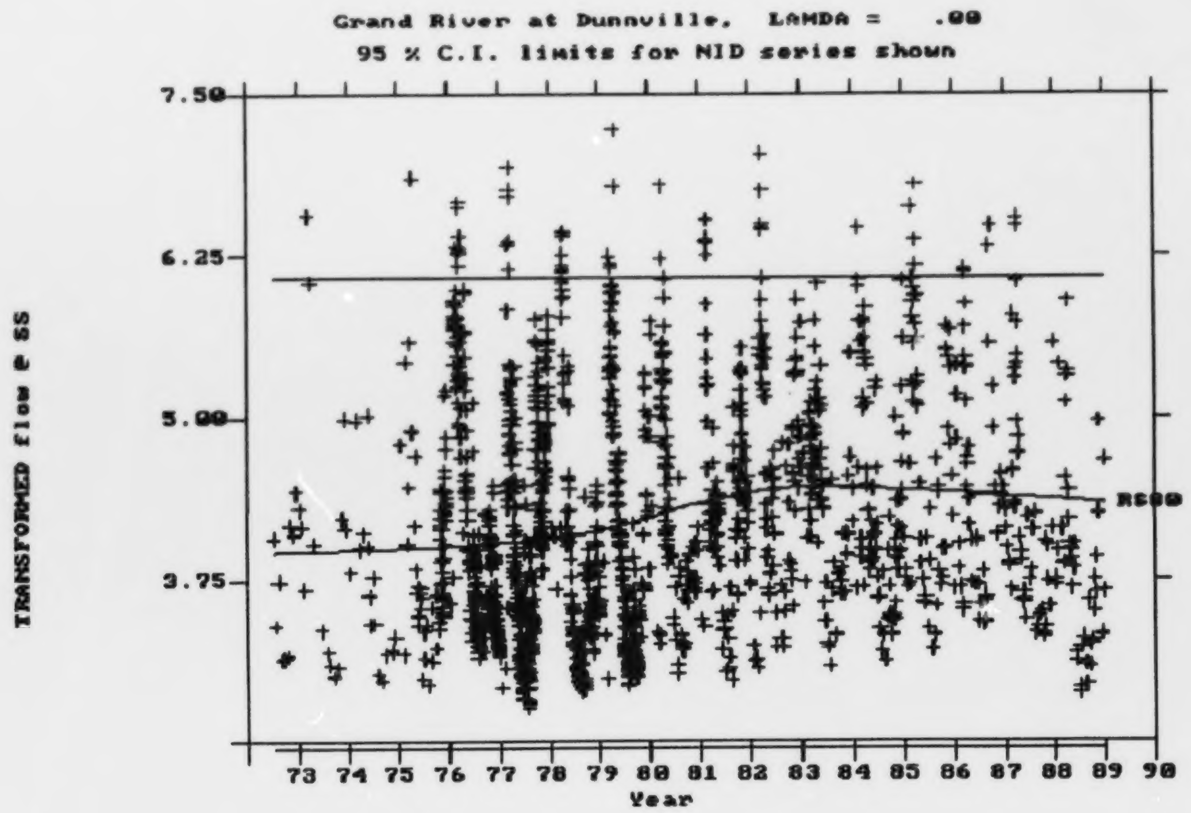


KENDALL RANK CORRELATION, TAU= .145, S.L. = 0.0000E+00

Grand.SS.9


TRANSFORMED SS
Grand River at Dunnville, LAMDA = .00
1.60
3.60
5.60
7.60
-0.25
1.00
2.25
3.50
detrended log flow
RS50
KENDALL RANK CORRELATION, TAU= .120, S.L. = 0.0000E+00

Grand.SS.10


Grand River at Dunnville, LAMDA = .00
95 % C.I. limits for NID series shown

MANN-KENDALL TEST, TAU= .109, S.L. = 0.0000E+00

Grand.SS.11

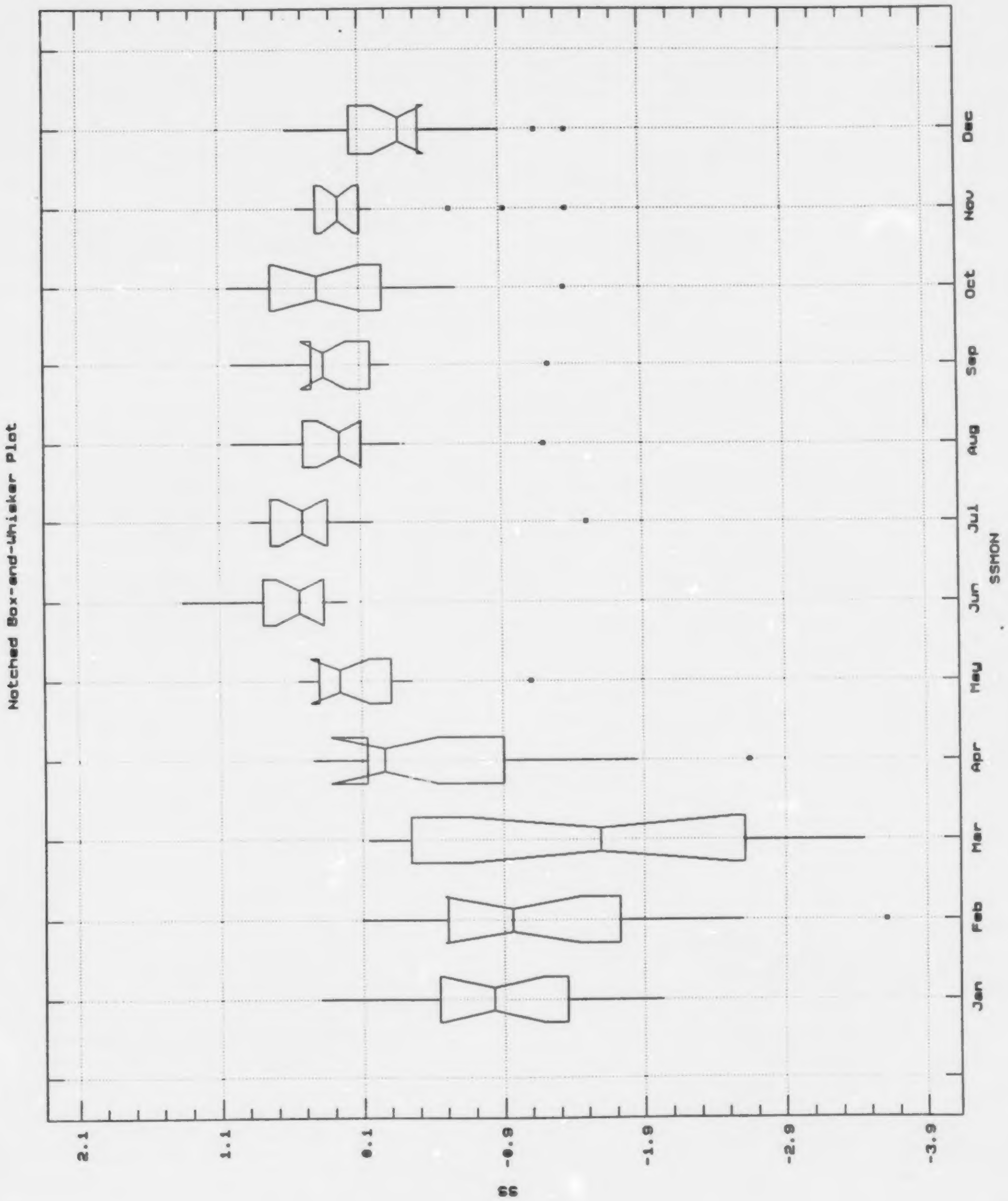
```
      Trend tests for mean monthly data


      Site: Grand River at Dunnville,

      parameter: SS

      Basic data - not adjusted for flow


      Mann-Kendall Trend Test
            tau           Significance Level
         -.02485                6.00490E-01


      Ordinary Spearman Trend Test
            rho           Significance Level
         -.02767                6.94848E-01


      Seasonal Mann-Kendall Trend Test
      Score          Variance                 Significance Level
       -79.             6879.0                          3.40844E-01


      Spearman Trend Test Partialling Out Seasonality

      Seasonal rankings:
  Season:    1  2  3  4  5  6  7  8  9 10 11 12
    Rank:    2  1  4  6  9  8  7  5  6  5  5  3

           rho           Significance Level
       -.02724                6.99320E-01
```

GRAND.SS.12

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of SS by SSMON
--------------------------------------------------------------------------------
Level        Sample Size    Average Rank
--------------------------------------------------------------------------------
 1             17          51.6471  2
 2             17          42.0000  1
 3             17          73.0000  4
 4             17          117.882  6
 5             16          160.313  9
 6             17          138.235  8
 7             16          127.813  7
 8             17          110.118  5
 9             17          116.235  6
 10             17          110.412  6
 11             17          107.765  5
 12             17          67.5882  3
--------------------------------------------------------------------------------
Test statistic = 69.2643  Significance level  = 1.68535E-10
```

```
    Trend tests for mean monthly data


    Site: Grand River at Dunnville,

    parameter: SS

    Flow-adjusted Data


    Mann-Kendall Trend Test
          tau          Significance Level
       -.01141              8.11721E-01


    Ordinary Spearman Trend Test
          rho          Significance Level
       -.01234              8.63164E-01


    Seasonal Mann-Kendall Trend Test
    Score            Variance          Significance Level
    -125.               6315.0                 1.15723E-01


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    3  2  1  4  6  9  8  7  7  7  6  5

         rho          Significance Level
     -.05205              4.67345E-01
```

Grand.SS.14


Notched Box-and-Whisker Plot
SS
2.1
1.1
0.1
-0.9
-1.9
-2.9
-3.9
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
SSMON

GRAND.SS.15

```
--------------------------------------------------------------------
Kruskal-Wallis analysis of SS by SSMON
--------------------------------------------------------------------
Level                Sample Size      Average Rank
--------------------------------------------------------------------
  1                       16              45.1250 3
  2                       16              38.6875 2
  3                       16              35.2500 1
  4                       16              69.3125 4
  5                       15              112.467 6
  6                       16              159.375 9
  7                       16              146.125 8
  8                       17              124.353 7
  9                       17              124.882 7
 10                       17              128.000 7
 11                       17              113.059 6
 12                       17              81.2941 5
--------------------------------------------------------------------
Test statistic = 101.19  Significance level   = 1.11022E-16
```

```
    Trend tests for mean monthly data


    Site: Grand River at Dunnville,

    parameter: SS

    Flow-adjusted Data


    Mann-Kendall Trend Test
          tau            Significance Level
       -.00031                9.93925E-01


    Ordinary Spearman Trend Test
          rho            Significance Level
        .00536                9.40302E-01


    Seasonal Mann-Kendall Trend Test
    Score            Variance            Significance Level
     -87.               6315.0                    2.73607E-01


    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    2  1  1  3  6  9  8  6  7  7  5  4

         rho           Significance Level
     -.01661                8.16560E-01
```

GRAND.SS.17

```
------------------------------------------------------------------------
Kruskal-Wallis analysis of SS by SSMON
------------------------------------------------------------------------
Level          Sample Size    Average Rank
------------------------------------------------------------------------
  1                16          46.2500  2
  2                16          38.1250  1
  3                16          41.1875  1
  4                16          73.3750  3
  5                15          118.867  6
  6                16          157.938  9
  7                16          145.125  8
  8                17          117.000  6
  9                17          123.059  7
 10                17          126.118  7
 11                17          111.000  5
 12                17          81.1176  4
------------------------------------------------------------------------
Test statistic = 92.9304  Significance level  = 4.44089E-15
```

Grand.ALK

Grand River at Dunnville

Alkalinity

Table of Contents: Grand.ALK

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs ALK

(9) Scatter and smooth of detrended-flow vs ALK

(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box-and-whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Summary and Conclusions

Grand River - ALK

Data Transformation: none

Seasonality: very strong

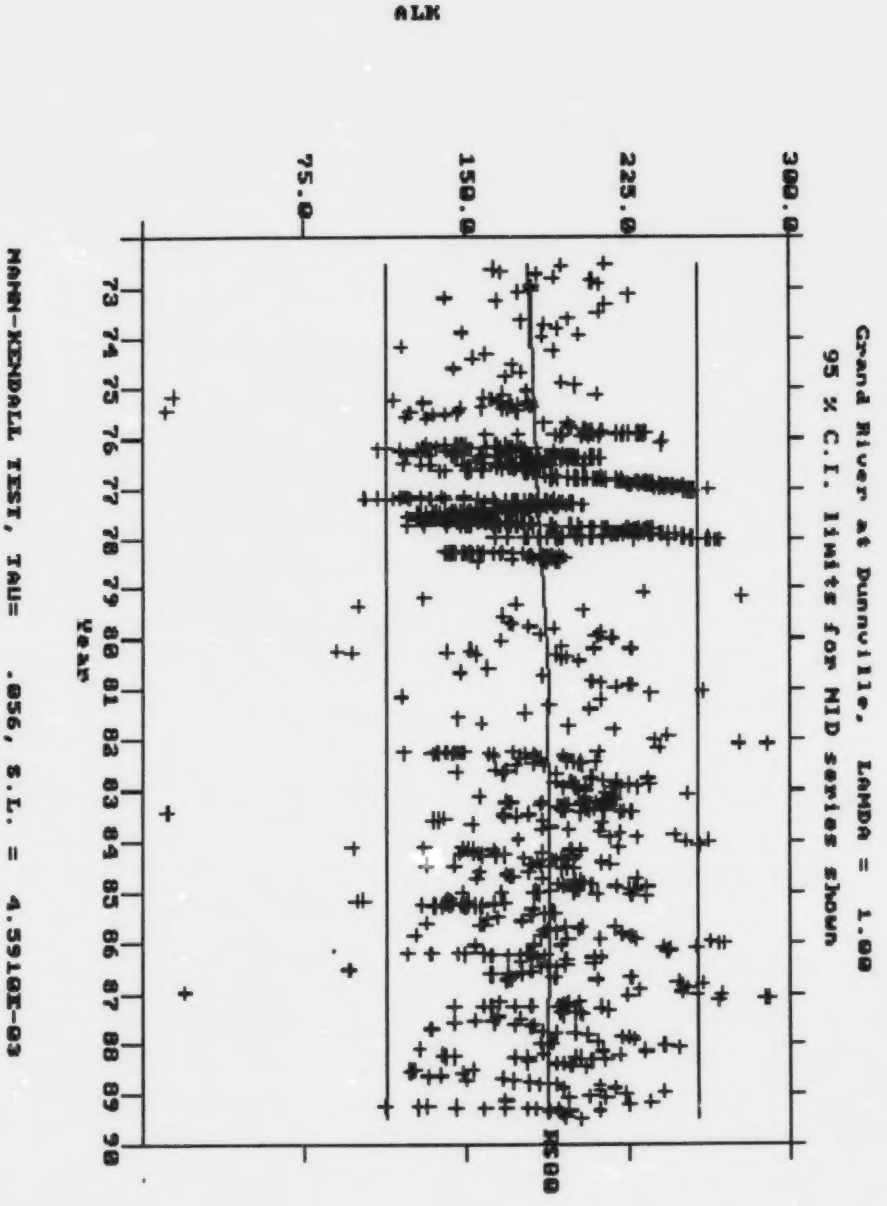
Flow-Concentration Relationship: Upside-down U-shaped behaviour coupled with two-branch behaviour as in SS. Seasonal model called for.

Outliers: none apparent

Trend: Strong upward trend from 1972-1980 with fairly constant value from 1981-1989 in the unadjusted and the detrended-flow-adjusted data. No trend in the flow-adjusted data.

Other:

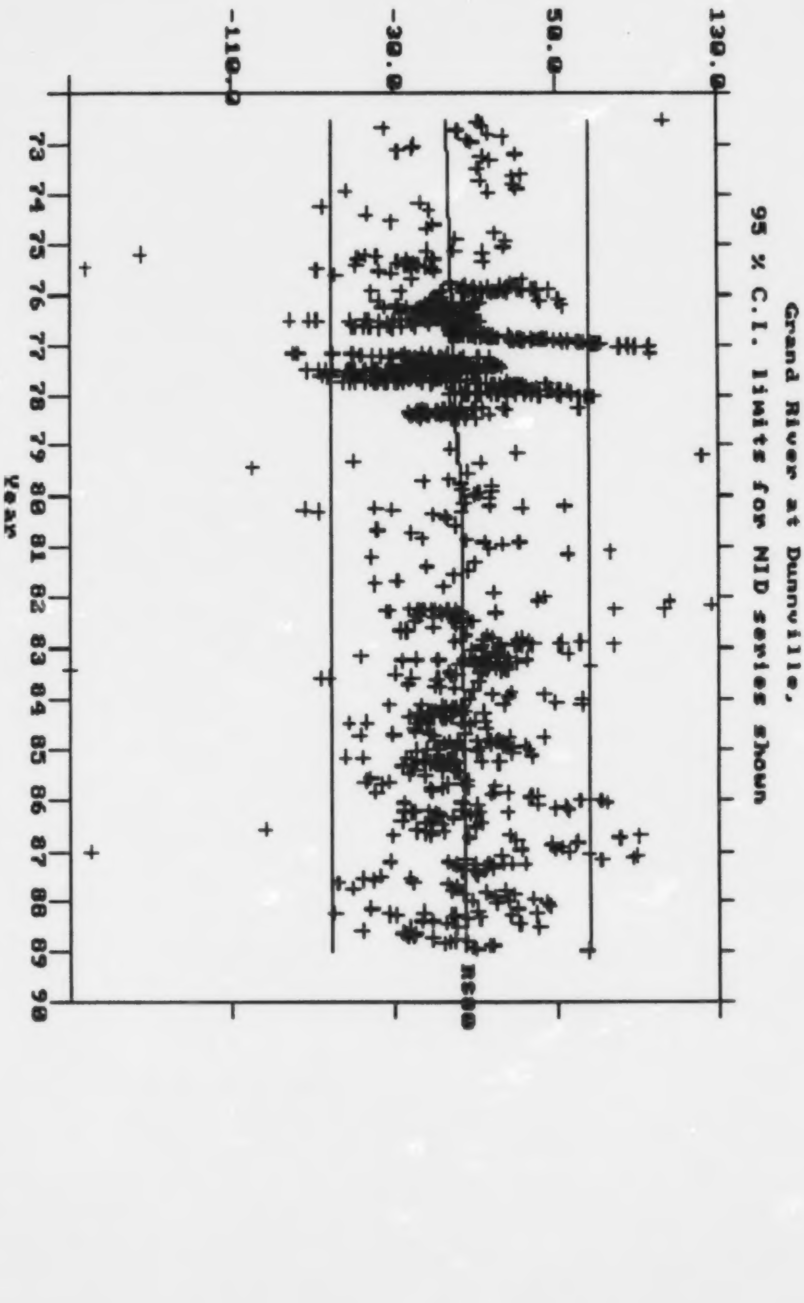
Grand.ALK.2


ALK
Grand River at Dunnville, LAMDA = 1.00
95 % C.I. limits for NID series shown
75.0
150.0
225.0
300.0
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Year
MANN-KENDALL TEST, TAU= .056, S.L. = 4.5910E-03

Flow-adjusted ALK

Grand River at Dunnville,

95 % C.I. limits for NID series shown

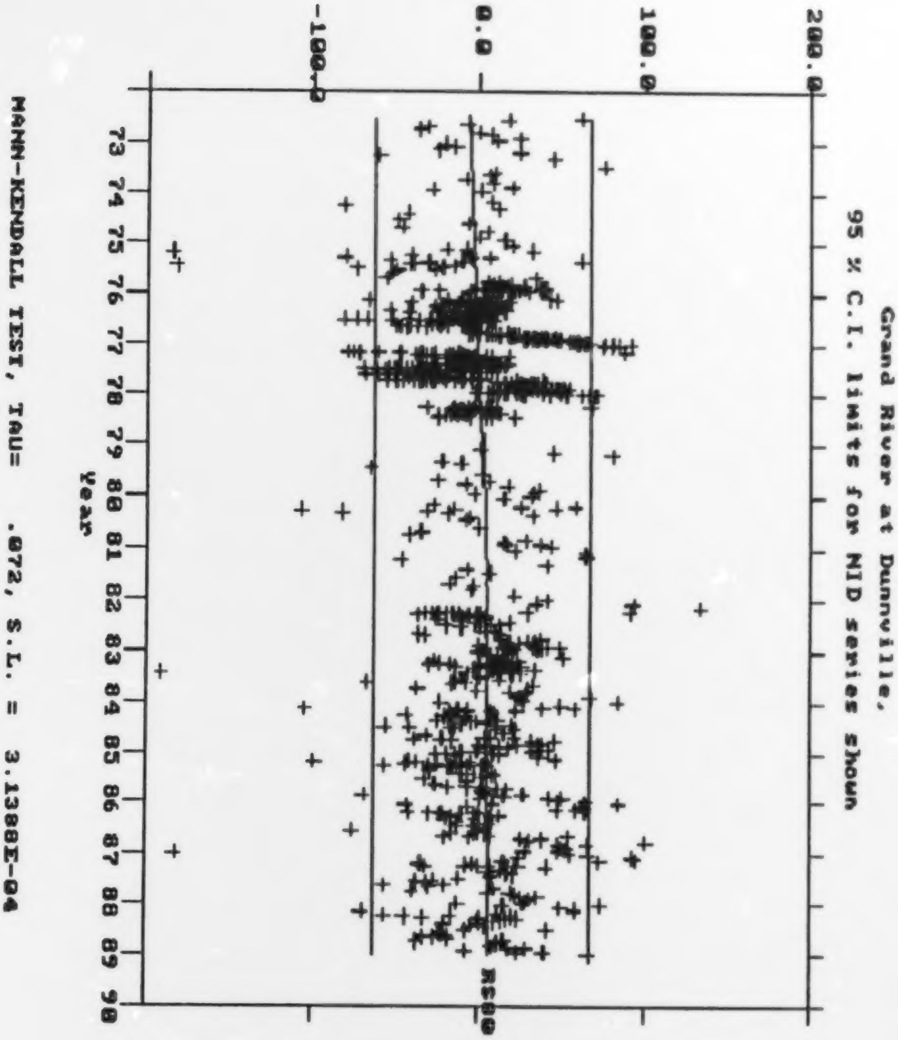


MANN-KENDALL TEST, TAU= .065, S.L. = 1.0830E-03

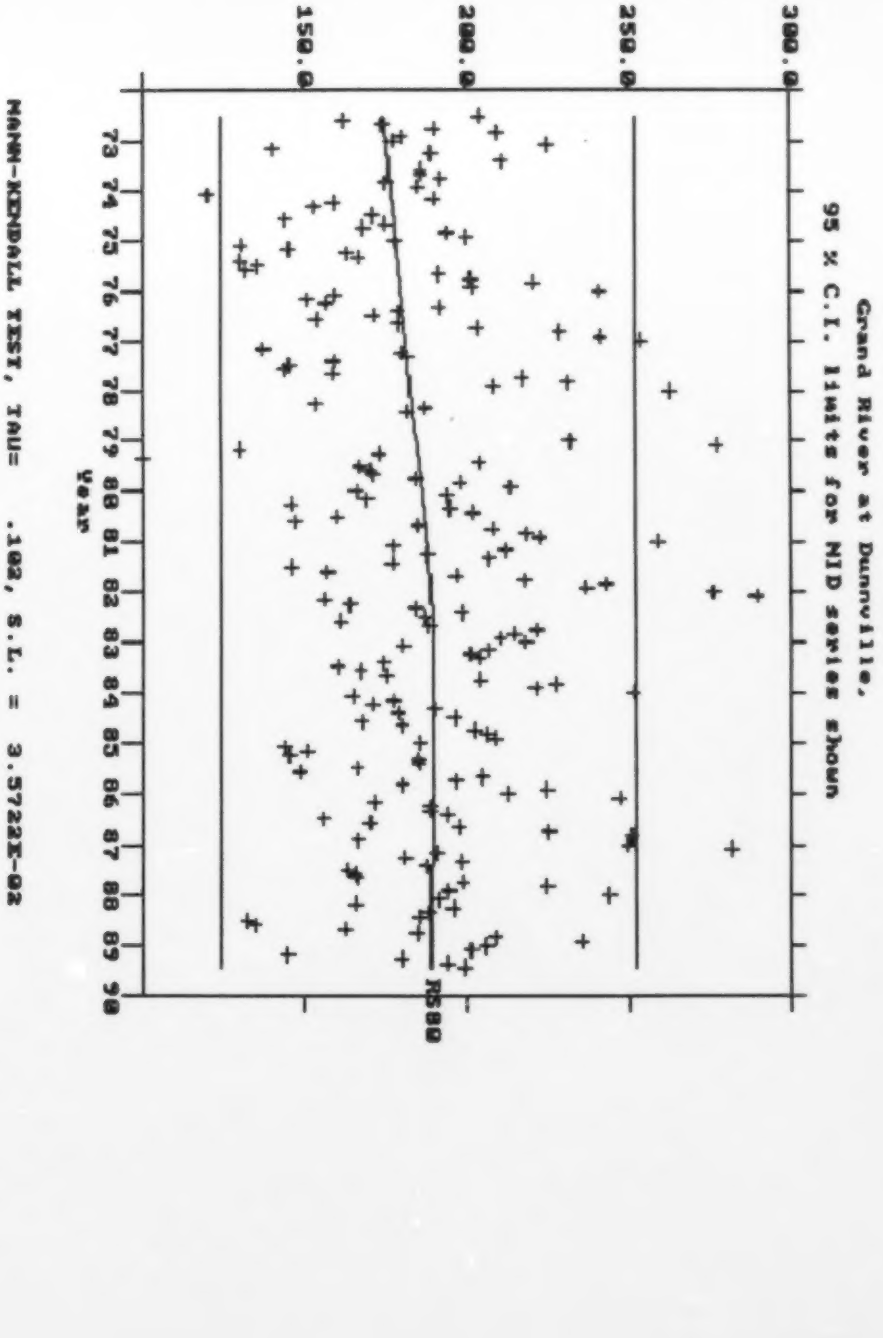
Grand.ALK.4

Detrended

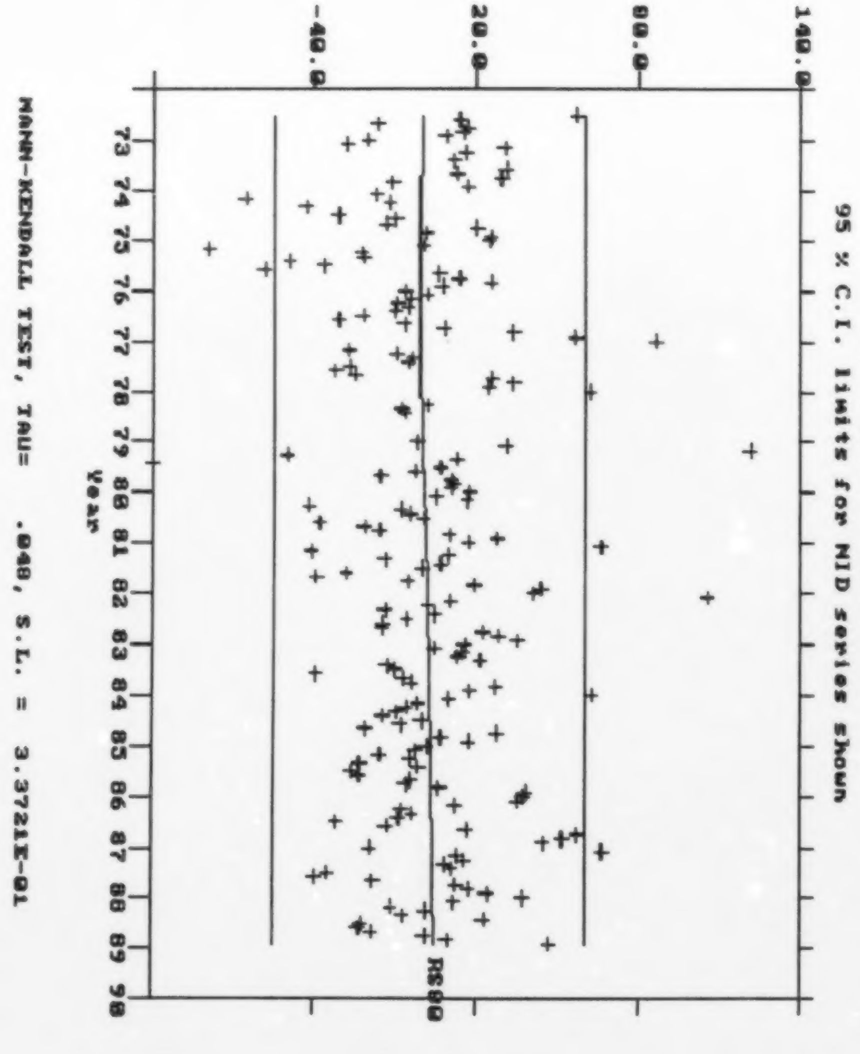
Flow-adjusted ALK



Monthly ALK

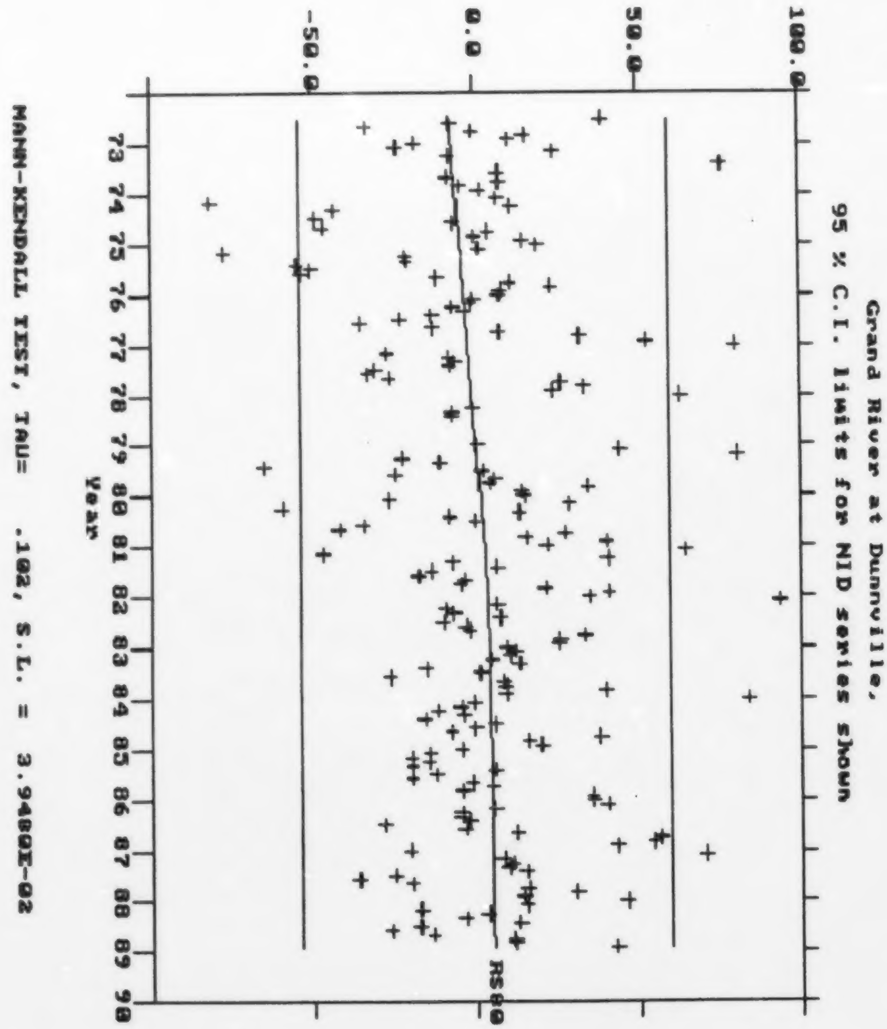

Grand River at Dunnville,
95 % C.I. limits for NID series shown
150.0
200.0
250.0
300.0
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Year
R580
MANN-KENDALL TEST, TAU= .102, S.L. = 3.5722E-02

Monthly Flow adjusted ALK

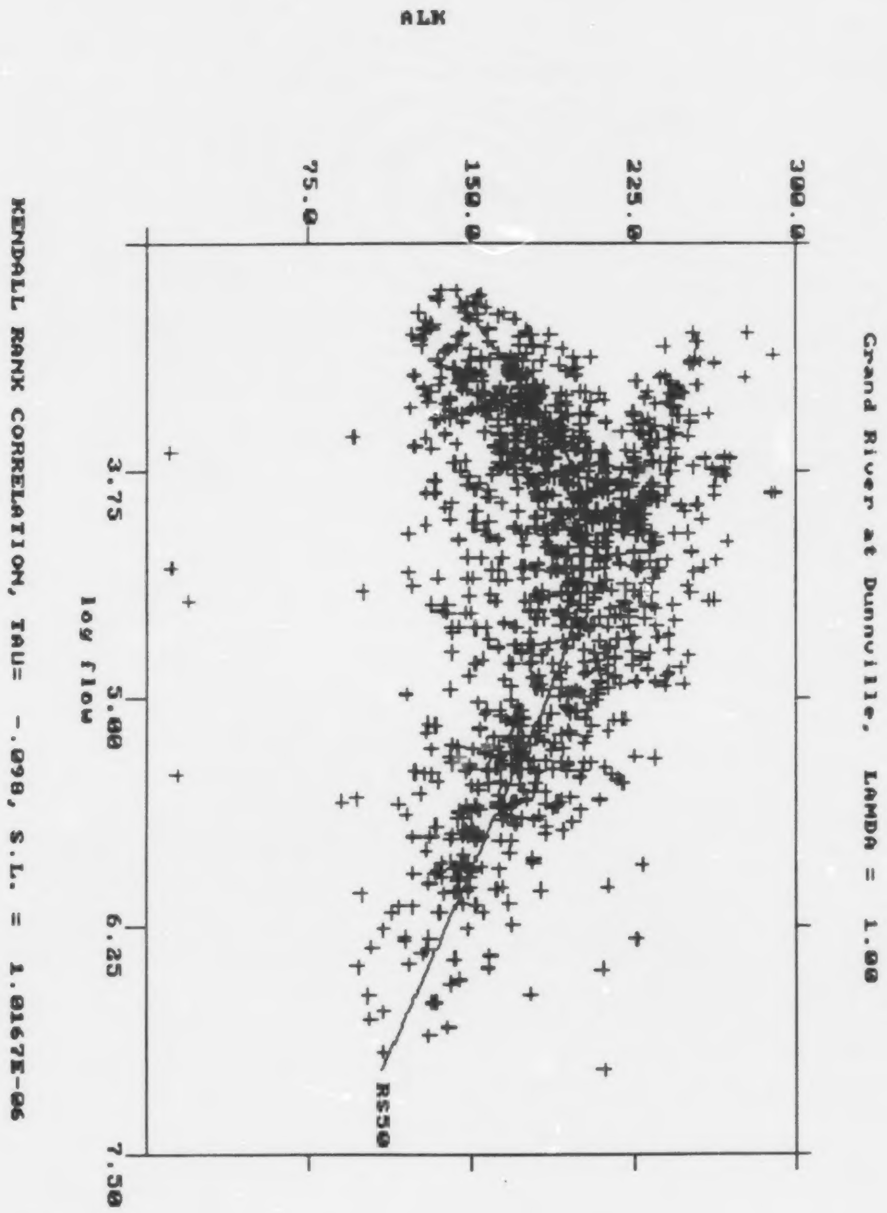


Grand.ALK.7

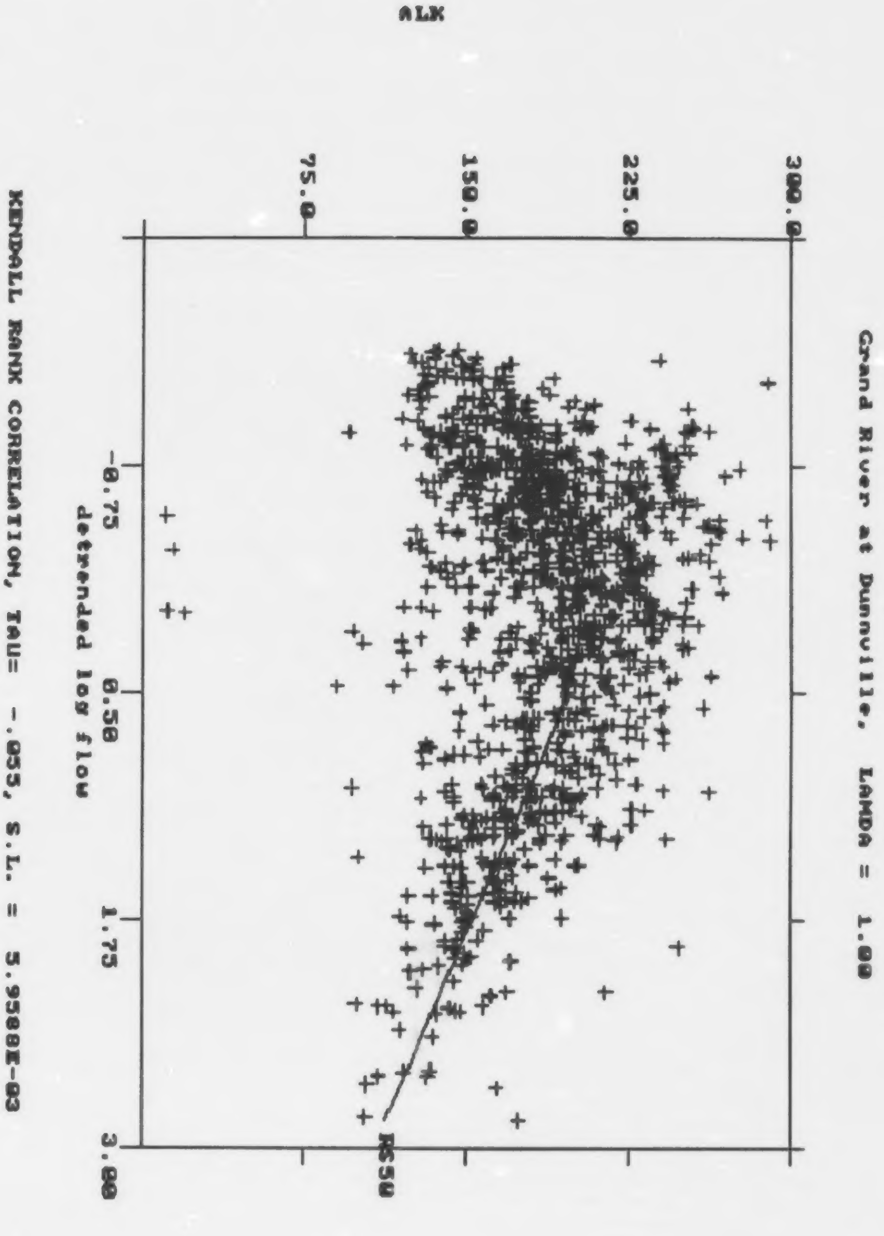
Monthly Flow-detrended ALK



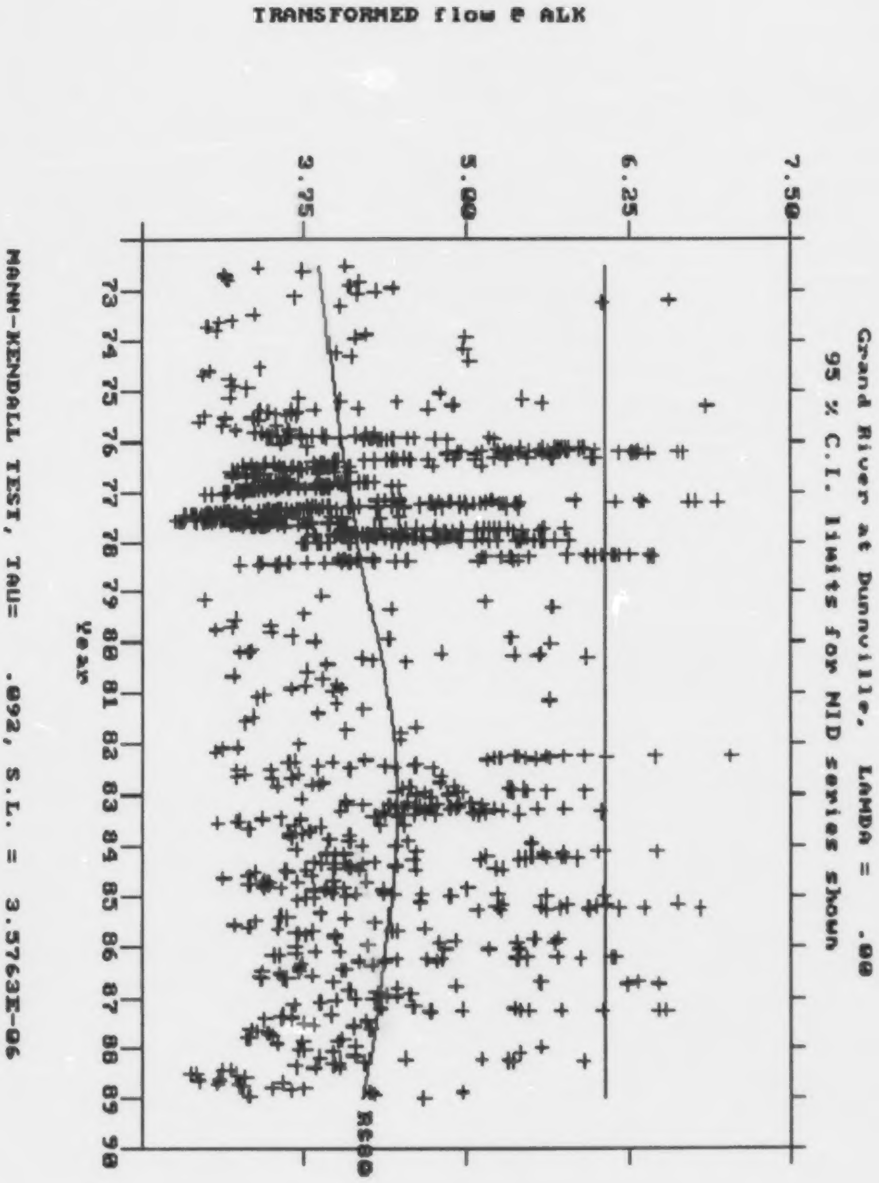
Grand.ALK.8


Grand River at Dunnville, LAMDA = 1.00
ALK
300.0
225.0
150.0
75.0
3.75
5.00
6.25
7.50
log flow
RS50
KENDALL RANK CORRELATION, TAU= -.098, S.L. = 1.0167E-06

Grand.ALK.9


Grand River at Dunnville, LAMDA = 1.00
ALK
75.0
150.0
225.0
300.0
-0.75
0.50
1.75
3.00
detrended log flow
R50
KENDALL RANK CORRELATION, TAU= -.055, S.L. = 5.9588E-03

Grand.ALK.10


TRANSFORMED flow @ ALK
Grand River at Dunnville, LAMDA = .00
95 % C.I. limits for NID series shown
3.75
5.00
6.25
7.50
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
Year
RS80
MANN-KENDALL TEST, TAU= .092, S.L. = 3.5763E-06

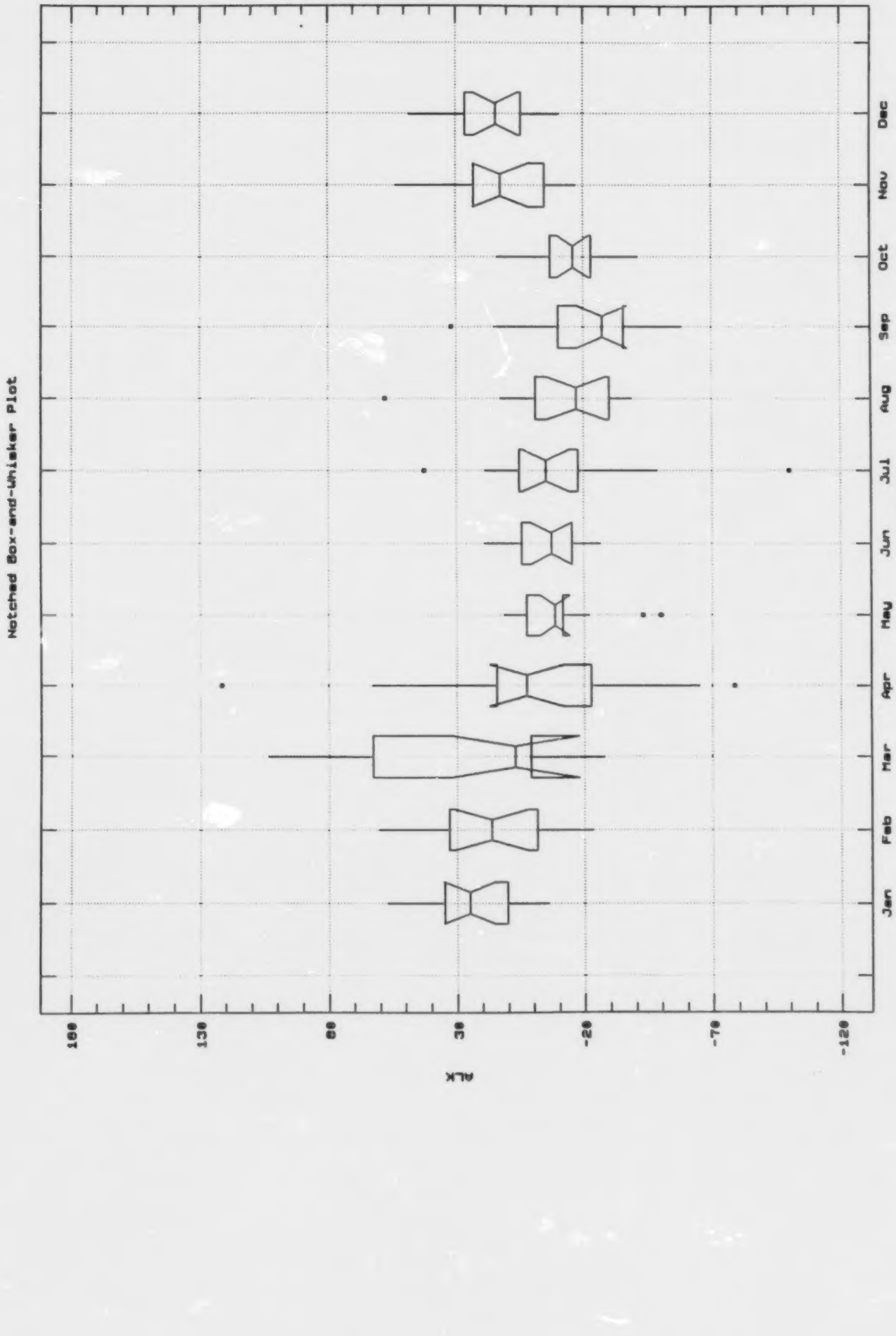
```
      Trend tests for mean monthly data


      Site: Grand River at Dunnville,

      parameter: ALK

      Basic data - not adjusted for flow


      Mann-Kendall Trend Test
            tau          Significance Level
          .10232               3.57224E-02


      Ordinary Spearman Trend Test
            rho          Significance Level
          .15444               3.32654E-02


      Seasonal Mann-Kendall Trend Test
      Score          Variance           Significance Level
       204.             5846.0                  7.62832E-03


      Spearman Trend Test Partialling Out Seasonality

      Seasonal rankings:
  Season:    1  2  3  4  5  6  7  8  9 10 11 12
    Rank:    8  8  6  3  3  5  4  2  1  4  7  9

           rho          Significance Level
        .14642               4.35649E-02
```

GRAND.ALK.12

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of ALK by ALKMON
--------------------------------------------------------------------------------
Level       Sample Size    Average Rank
--------------------------------------------------------------------------------
  1            16           140.938  8
  2            15           143.867  8
  3            16           105.938  6
  4            17           62.4706  3
  5            16           63.1250  3
  6            16           98.2500  5
  7            15           81.6000  4
  8            16           58.0000  2
  9            16           37.3125  1
 10             16           84.6875  4
 11             16           130.438  7
 12             16           149.563  9
--------------------------------------------------------------------------------
Test statistic = 82.785  Significance level  = 4.25993E-13
```

```
Trend tests for mean monthly data

Site: Grand River at Dunnville,

parameter: ALK

Flow-adjusted Data


Mann-Kendall Trend Test
      tau           Significance Level
    .04759               3.37207E-01


Ordinary Spearman Trend Test
      rho           Significance Level
    .07373               3.17219E-01


Seasonal Mann-Kendall Trend Test
Score           Variance          Significance Level
 106.              5335.3                  1.46726E-01


Spearman Trend Test Partialling Out Seasonality

Seasonal rankings:
Season:    1  2  3  4  5  6  7  8  9 10 11 12
  Rank:    7  5  5  4  3  3  3  2  1  2  5  6

     rho           Significance Level
  .06803               3.56096E-01
```

Grand.ALK.14


Notched Box-and-Whisker Plot
ALK
180
130
80
30
-20
-70
-120
ALKMON
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

GRAND.ALK.15

```
------------------------------------------------------------
Kruskal-Wallis analysis of ALK by ALKMON
------------------------------------------------------------
Level              Sample Size     Average Rank
------------------------------------------------------------
  1                     15            145.267 7
  2                     14            123.357 5
  3                     15            121.467 5
  4                     16            90.3125 4
  5                     15            72.0667 3
  6                     15            78.6667 3
  7                     15            73.5333 3
  8                     16            61.1250 2
  9                     16            46.0000 1
 10                     16            58.5000 2
 11                     16            119.875 5
 12                     16            131.250 6
------------------------------------------------------------
Test statistic = 65.2478  Significance level   = 9.67929E-10
```

Grand.ALK.16

```
    Trend tests for mean monthly data

    Site: Grand River at Dunnville,

    parameter: ALK

    Flow-adjusted Data

    Mann-Kendall Trend Test
          tau          Significance Level
        .10188              3.94801E-02

    Ordinary Spearman Trend Test
          rho          Significance Level
        .15795              3.21493E-02

    Seasonal Mann-Kendall Trend Test
    Score          Variance          Significance Level
     256.             5335.3                  4.57048E-04

    Spearman Trend Test Partialling Out Seasonality

    Seasonal rankings:
Season:   1  2  3  4  5  6  7  8  9 10 11 12
  Rank:   7  5  5  4  3  3  3  2  1  2  6  7

         rho         Significance Level
      .16634              2.40527E-02
```

GRAND.ALK.17

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of ALK by ALKMON
--------------------------------------------------------------------------------
Level          Sample Size    Average Rank
--------------------------------------------------------------------------------
  1              15          142.067  7
  2              14          120.571  5
  3              15          122.333  5
  4              16          83.6250  4
  5              15          74.2667  3
  6              15          74.0667  3
  7              15          71.3333  3
  8              16          62.1875  2
  9              16          44.4375  1
 10               16          59.0000  2
 11               16          128.000  6
 12               16          138.750  7
--------------------------------------------------------------------------------
Test statistic = 70.884  Significance level  = 8.29413E-11
```

Grand.CND

Grand River at Dunnville

Conductivity

Table of Contents: Grand.CND

(1) Summary and conclusions

(2) Trace and smooth of unadjusted data

(3) Trace and smooth of flow-adjusted data

(4) Trace and smooth of detrended-flow-adjusted data

(5) Trace and smooth of mean monthly unadjusted data

(6) Trace and smooth of mean monthly flow-adjusted data

(7) Trace and smooth of mean monthly detrended-flow-adjusted data

(8) Scatter and smooth of flow vs CND

(9) Scatter and smooth of detrended-flow vs CND

(10) Trace and smooth of the flow covariate

(11) Trend tests on monthly unadjusted data

(12) Kruskal-Wallis test for seasonality and seasonal rankings on detrended unadjusted data

(13) Trend tests on monthly flow-adjusted data

(14) Box-and-whisker plot of detrended flow-adjusted data

(15) Kruskal-Wallis test for seasonality and seasonal rankings on detrended flow-adjusted data

(16) Trend tests on monthly detrended-flow-adjusted data

(17) Kruskal-Wallis test for seasonality and seasonal rankings on detrended detrended-flow-adjusted data

Summary and Conclusions

Grand River - CND

Data Transformation: none

Seasonality: very strong

Flow-Concentration Relationship: constant at low flow and negatively related at moderate to large flow

Outliers: none apparent

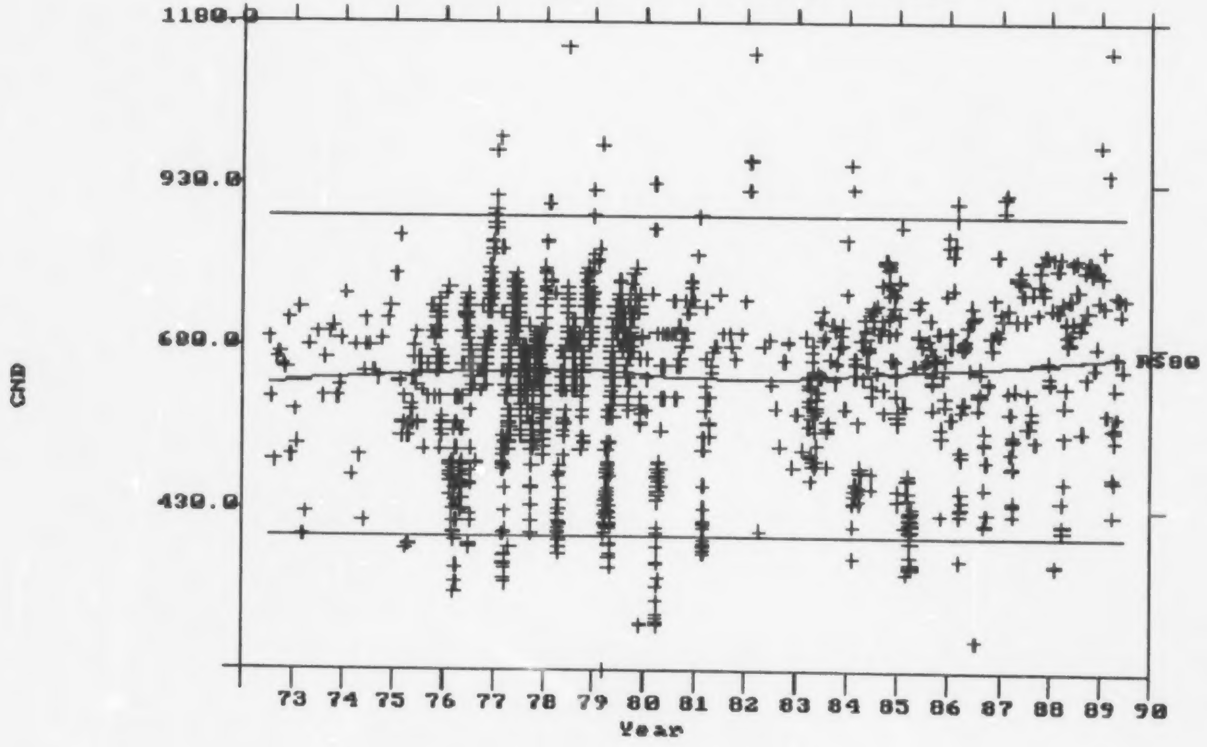
Trend: Some upward trend. In unadjusted data, the biggest increase is from 1972-1979 while for the flow-adjusted and detrended-flow-adjusted the trend is upward at about the same rate over the entire period 1972-1989. Strongest trend effect observed in the flow-adjusted data.

Other:

Grand.CND.2

Grand River at Dunnville, LAMDA = 1.00

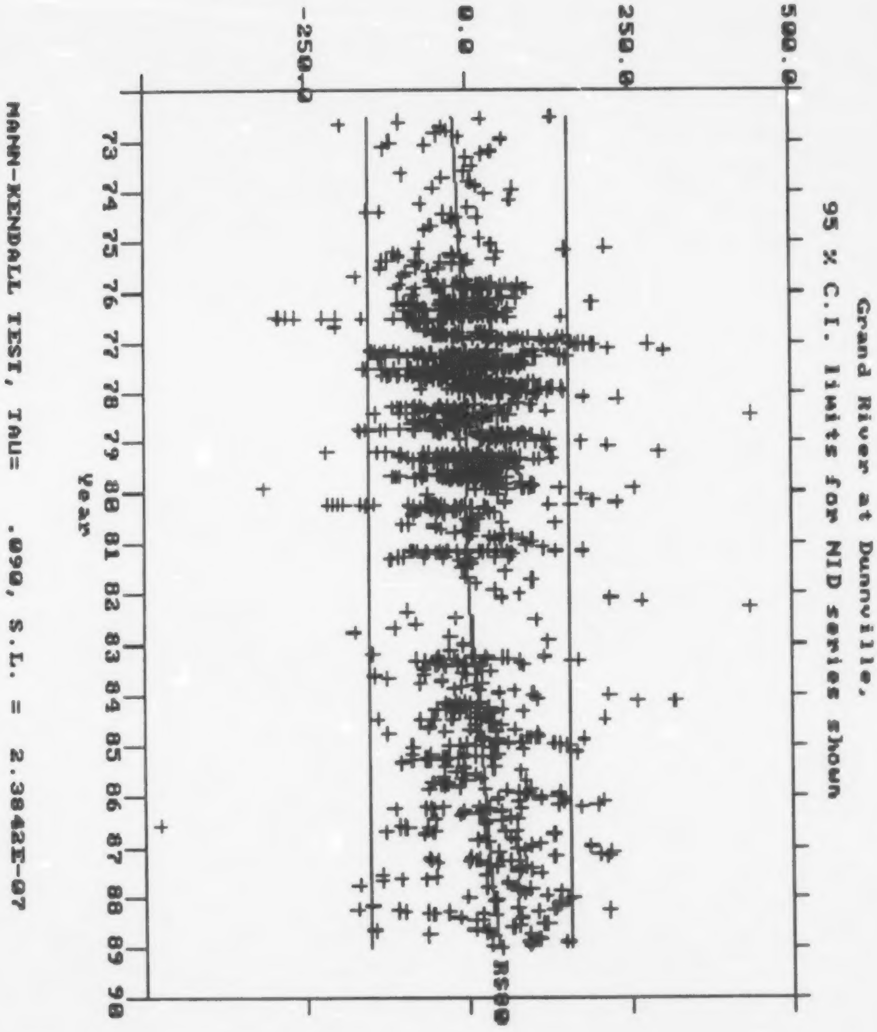
95 % C.I. limits for NID series shown



MANN-KENDALL TEST, TAU= .028, S.L. = 1.0803E-01

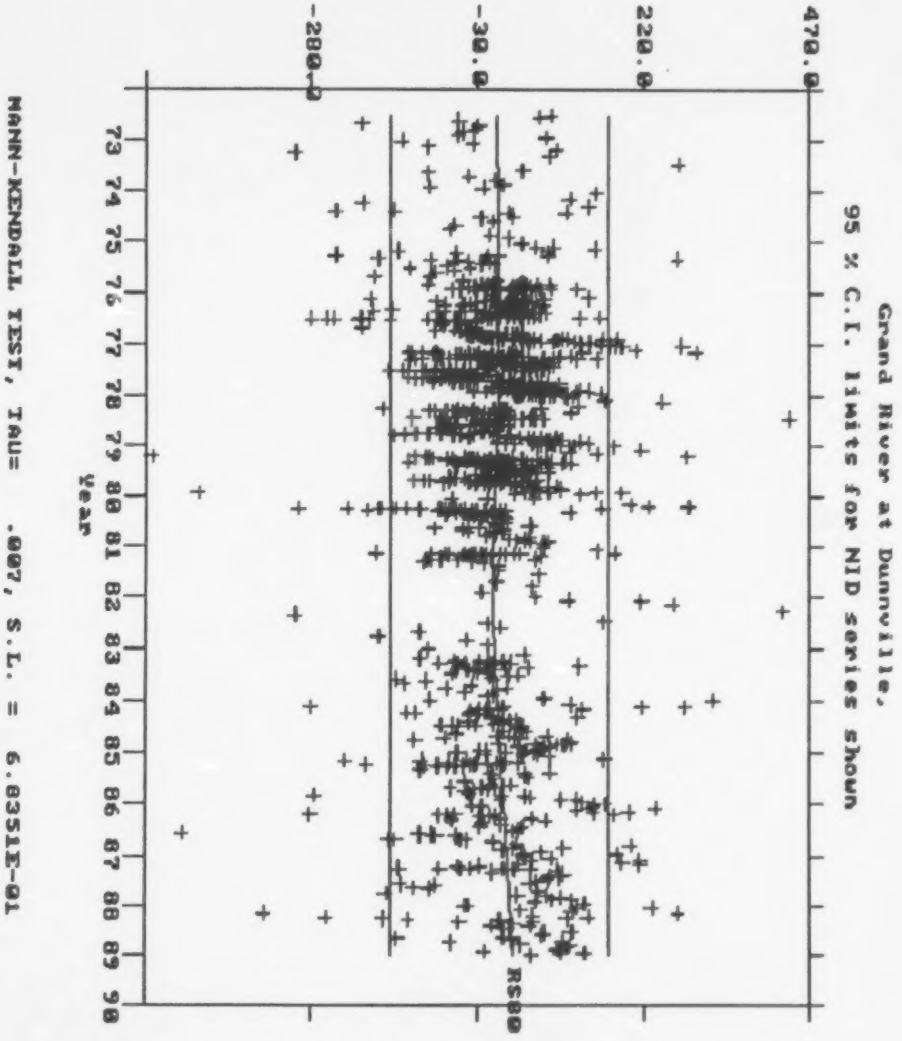
Grand.CND.3

Flow-adjusted CND



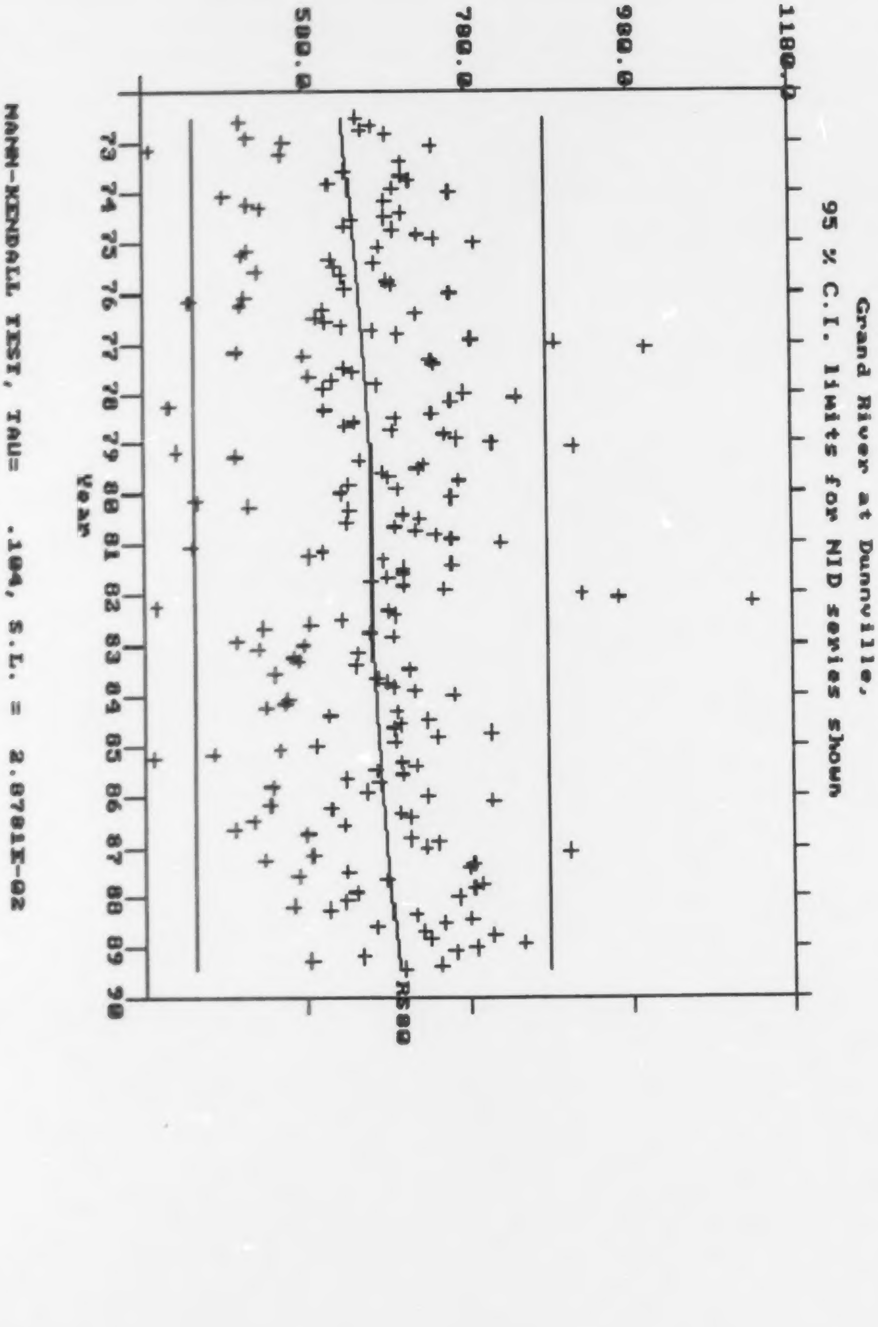
Detrended

Flow-adjusted CND



Grand.CND.5

Monthly CND

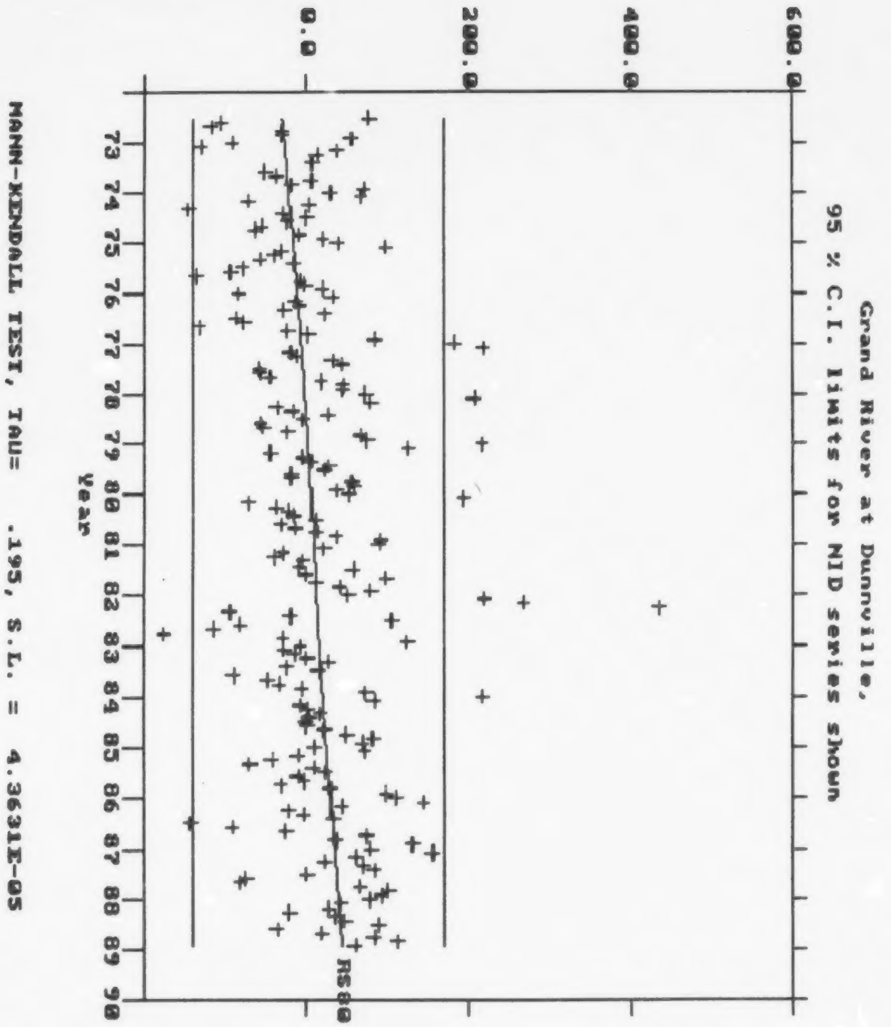

Grand River at Dunnville,

95 % C.I. limits for NID series shown

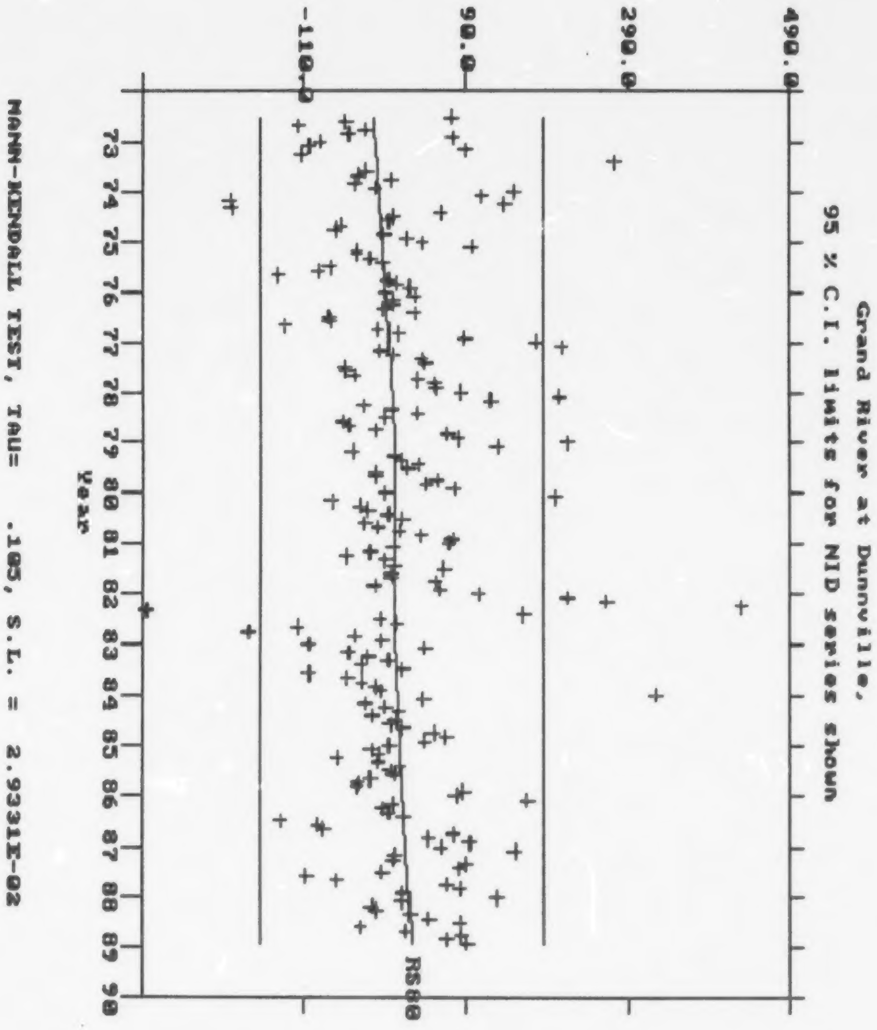
MANN-KENDALL TEST, TAU= .104, S.L. = 2.8781E-02

Grand.CND.6

Monthly Flow adjusted CND

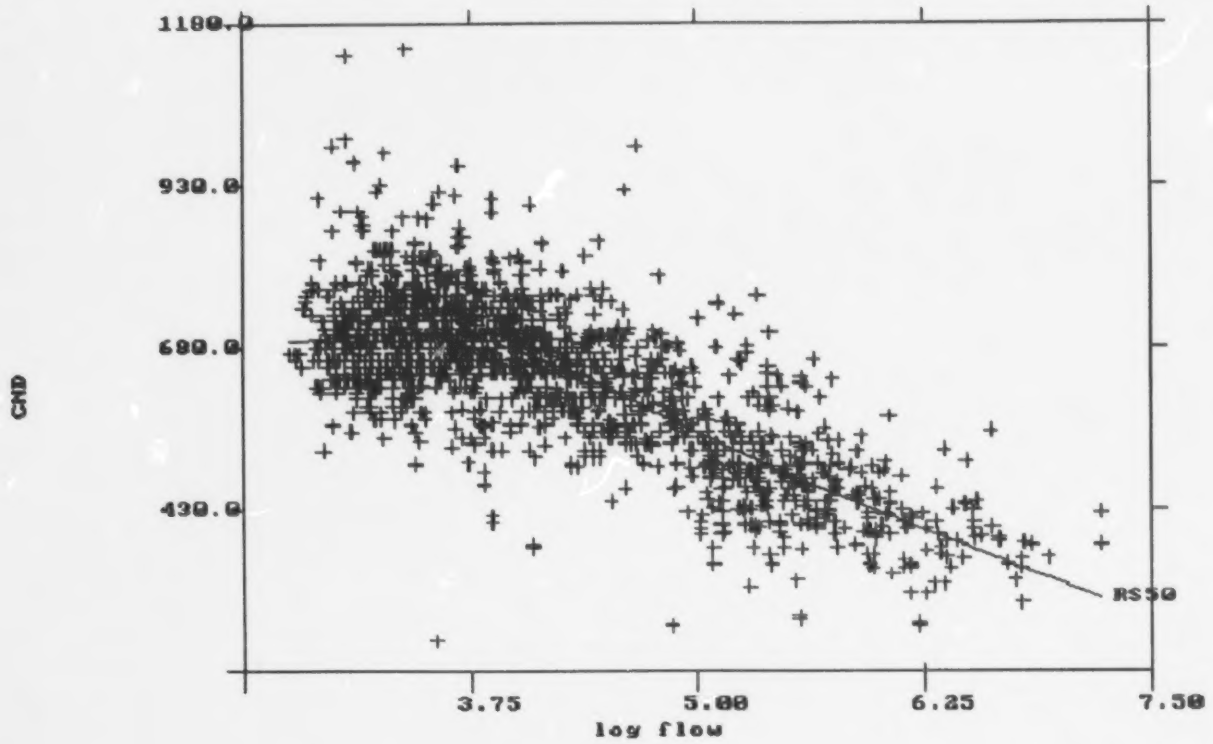


Monthly Flow-detrended CND



Grand.CND.8

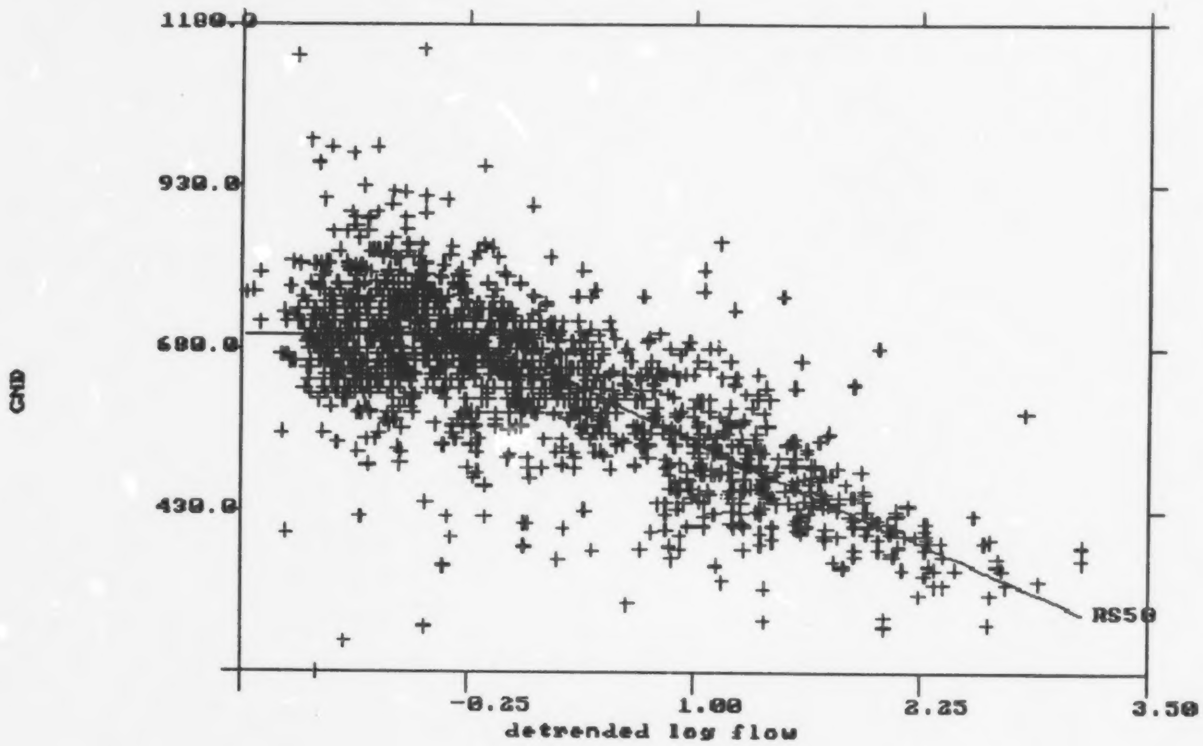
Grand River at Dunnville, LAMDA = 1.00



KENDALL RANK CORRELATION, TAU= -.493, S.L. = 0.0000E+00

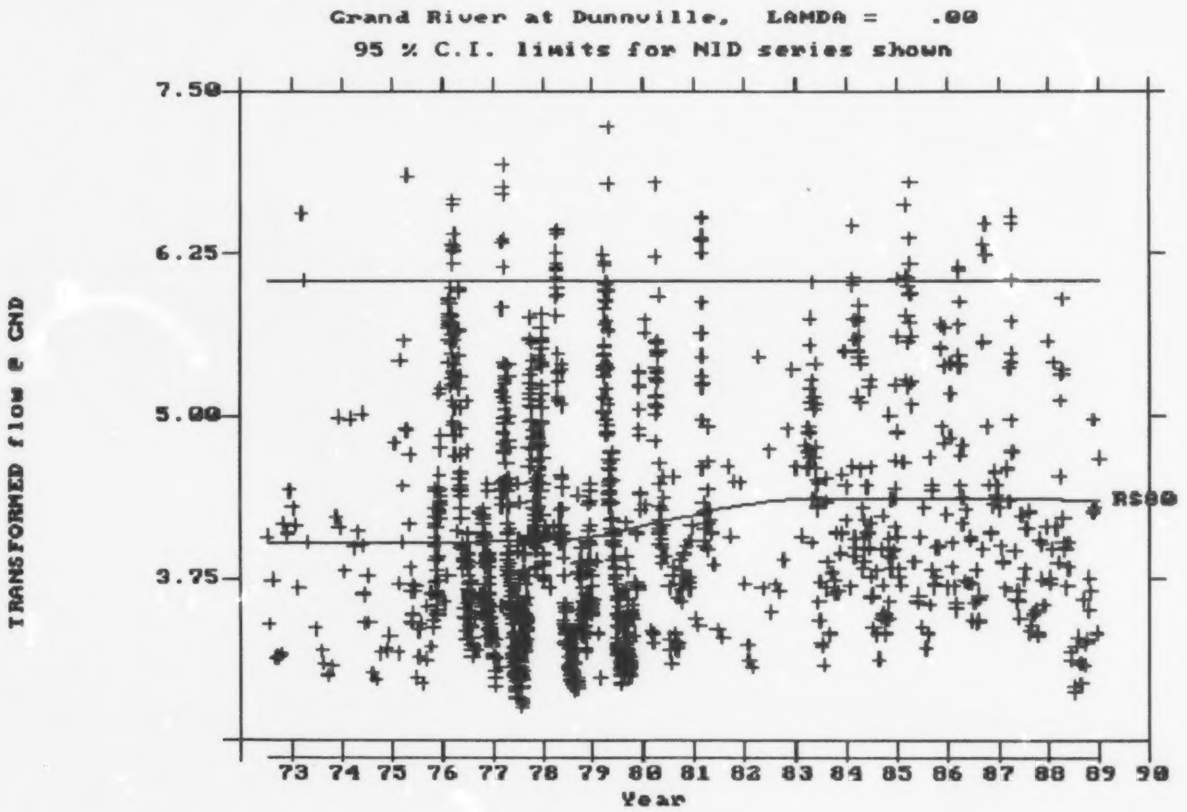
Grand.CND.9

Grand River at Dunnville, LAMDA = 1.00



KENDALL RANK CORRELATION, TAU= -.491, S.L. = 0.0000E+00

Grand.CND.10



MANN-KENDALL TEST, TAU= .066, S.L. = 1.4770E-04

Grand.CND.11

```
Trend tests for mean monthly data


Site: Grand River at Dunnville,

parameter: CND

Basic data - not adjusted for flow


Mann-Kendall Trend Test
      tau            Significance Level
    .10364                2.87811E-02


Ordinary Spearman Trend Test
      rho            Significance Level
    .15357                2.94679E-02


Seasonal Mann-Kendall Trend Test
Score              Variance             Significance Level
 287.                 6872.3                      5.36084E-04


Spearman Trend Test Partialling Out Seasonality

Seasonal rankings:
    Season:   1  2  3  4  5  6  7  8  9 10 11 12
      Rank:   8 10  7  2  1  5  9  6  3  4  8  8

          rho          Significance Level
        .16049                2.28840E-02
```

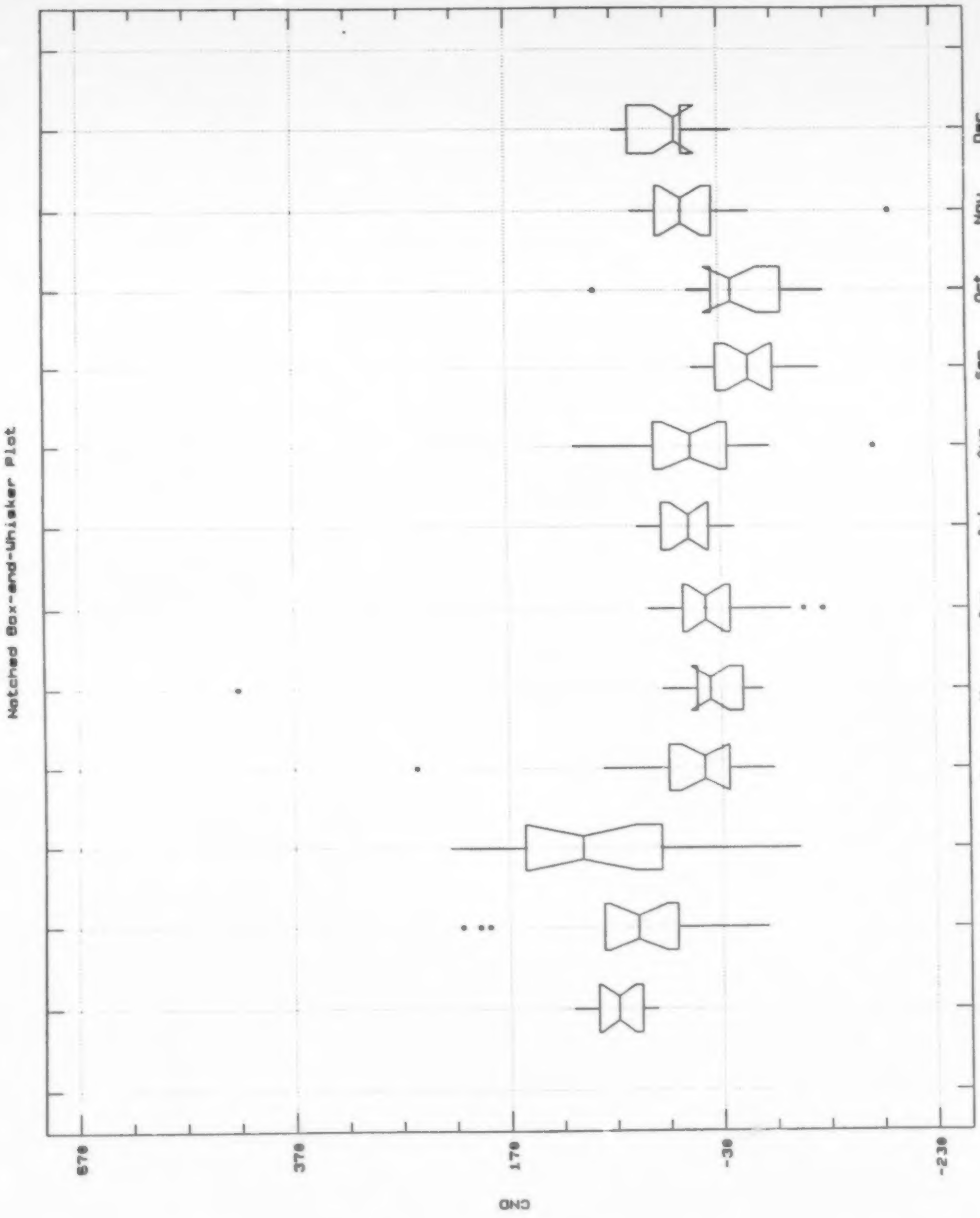
GRAND.CND.12

```
-------------------------------------------------------------------------
Kruskal-Wallis analysis of CND by CNDMON
-------------------------------------------------------------------------
Level        Sample Size    Average Rank
-------------------------------------------------------------------------
 1              17            122.294  8
 2              17            148.529  10
 3              17            117.529  7
 4              17            54.2353  2
 5              16            25.8125  1
 6              17            94.5882  5
 7              16            134.375  9
 8              17            106.529  6
 9              17            73.8235  3
10              17            87.9412  4
11              17            124.471  8
12              17            125.353  8
-------------------------------------------------------------------------
Test statistic = 67.9737  Significance level  = 2.96035E-10
```

Grand.CND.13

```
     Trend tests for mean monthly data


     Site: Grand River at Dunnville,

     parameter: CND

     Flow-adjusted Data


     Mann-Kendall Trend Test
           tau              Significance Level
         .19519                  4.36306E-05


     Ordinary Spearman Trend Test
           rho              Significance Level
         .28173                  8.35657E-05


     Seasonal Mann-Kendall Trend Test
     Score           Variance              Significance Level
      405.              6315.0                     3.57628E-07


     Spearman Trend Test Partialling Out Seasonality

     Seasonal rankings:
 Season:    1  2  3  4  5  6  7  8  9 10 11 12
   Rank:    9  7  8  4  3  3  5  5  1  2  5  6

          rho           Significance Level
       .30401                  2.18153E-05
```

Grand.CND.14


Notched Box-and-Whisker Plot
570
370
170
-30
-230
CND
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
CNDMON

```
-------------------------------------------------------------
Kruskal-Wallis analysis of CND by CNDMON
-------------------------------------------------------------
Level              Sample Size      Average Rank
-------------------------------------------------------------
  1                     16              162.000 9
  2                     16              135.750 7
  3                     16              151.125 8
  4                     16              88.8750 4
  5                     15              73.6000 3
  6                     16              76.4375 3
  7                     16              99.0000 5
  8                     17              95.1765 5
  9                     17              37.8824 1
 10                     17              49.0000 2
 11                     17              94.6471 5
 12                     17              122.765 6
-------------------------------------------------------------
Test statistic = 82.1004  Significance level  = 5.78426E-13
```

Grand.CND.16

```
Trend tests for mean monthly data


Site: Grand River at Dunnville,

parameter: CND

Flow-adjusted Data


Mann-Kendall Trend Test
      tau           Significance Level
    .10466               2.93313E-02


Ordinary Spearman Trend Test
      rho           Significance Level
    .14308               4.57134E-02


Seasonal Mann-Kendall Trend Test
Score           Variance          Significance Level
 215.              6315.0                  6.81961E-03


Spearman Trend Test Partialling Out Seasonality

Seasonal rankings:
Season:   1  2  3  4  5  6  7  8  9 10 11 12
  Rank:   7  7  8  3  3  3  6  4  2  1  4  5

     rho          Significance Level
   .15005              3.61454E-02
```

GRAND.CND.17

```
--------------------------------------------------------------------------------
Kruskal-Wallis analysis of CND by CNDMON
--------------------------------------------------------------------------------
Level        Sample Size    Average Rank
--------------------------------------------------------------------------------
 1            16          138.375   7
 2            16          137.375   7
 3            16          145.875   8
 4            16          78.0000   3
 5            15          80.8000   3
 6            16          80.7500   3
 7            16          121.438   6
 8            17          96.6471   4
 9            17          53.0588   2
 10            17          44.5294   1
 11            17          101.647   4
 12            17          107.941   5
--------------------------------------------------------------------------------
Test statistic = 61.155  Significance level  = 5.6533E-9
```